Validation of the Spectral Radiances and Forward Model for TES

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and

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For Passive Remote Sensing-
Retrieval of an Accurate Temperature Profile is Critical

Focus of this presentation

Uniformly mixed gas: Carbon Dioxide

Improvement in Forward Model: P - R Line Mixing for CO_2

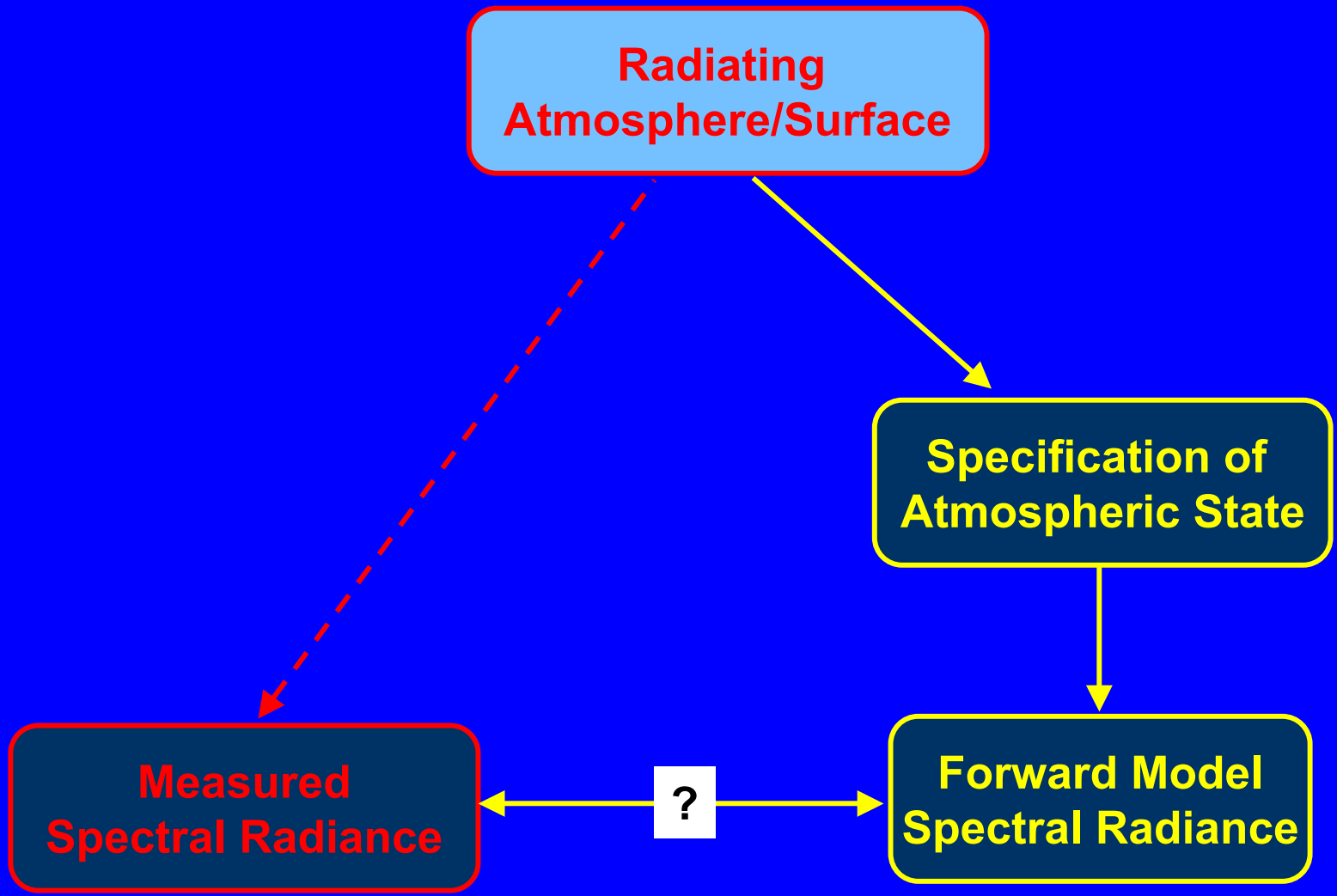
Acknowledgments

- **University of Wisconsin**

  Hank Revercomb, Bob Knuteson and Dave Tobin

- **JPL**

  TES Algorithm Development Team


Radiating
Atmosphere/Surface
Specification of
Atmospheric State
Measured
Spectral Radiance
?
Forward Model
Spectral Radiance

Remote Sensing

- **Measurements**
  - High Resolution Spectral Radiances
  - Upwelling/Downwelling

- **Forward Model (lblrtm)**
  - Atmospheric State
    - Layering, Pressure, Temperature and Column Amounts
  - Layer Optical Depths
    - Line Parameters (Line Coupling)
    - Line Shape
    - Continuum
  - Radiative Transfer
  - Instrument Function

- **Model/Measurement Comparisons**
  - Truth ?

- Temperature / Clear Sky

Instruments

- **AERI Atmospheric Emittance Radiometric Interferometer**
  - U. of Wisconsin — Interferometer
  - Downwelling Radiance — ARM/Surface — Resolution: 0.5 cm^{-1}

- **(S)HIS (Scanning) High-resolution Interferometer Sounder**
  - U. of Wisconsin — Interferometer
  - Upwelling Radiance — ER-2/WB-57 — Resolution: 0.5 cm^{-1}

- **TES Tropospheric Emission Spectrometer**
  - JPL — Interferometer
  - Upwelling Radiance — AURA — Resolution: 0.06 cm^{-1}

- **AIRS Atmospheric InfraRed Sounder**
  - JPL/NASA — Grating Array
  - Upwelling Radiance — AQUA — Resolution: 0.5 - 2 cm^{-1}

Spectral Radiance Measurements

- **The retrieval of atmospheric parameters with InfraRed Remote Sensing is a Poorly Posed Problem**
- **High Accuracy in the Forward Model and the Measured Radiances is Essential**
- **'Truth' at the Level Required is not readily available**
  - sonde accuracies; spatial and temporal sampling
  - laboratory measurements

What is 'Truth'?

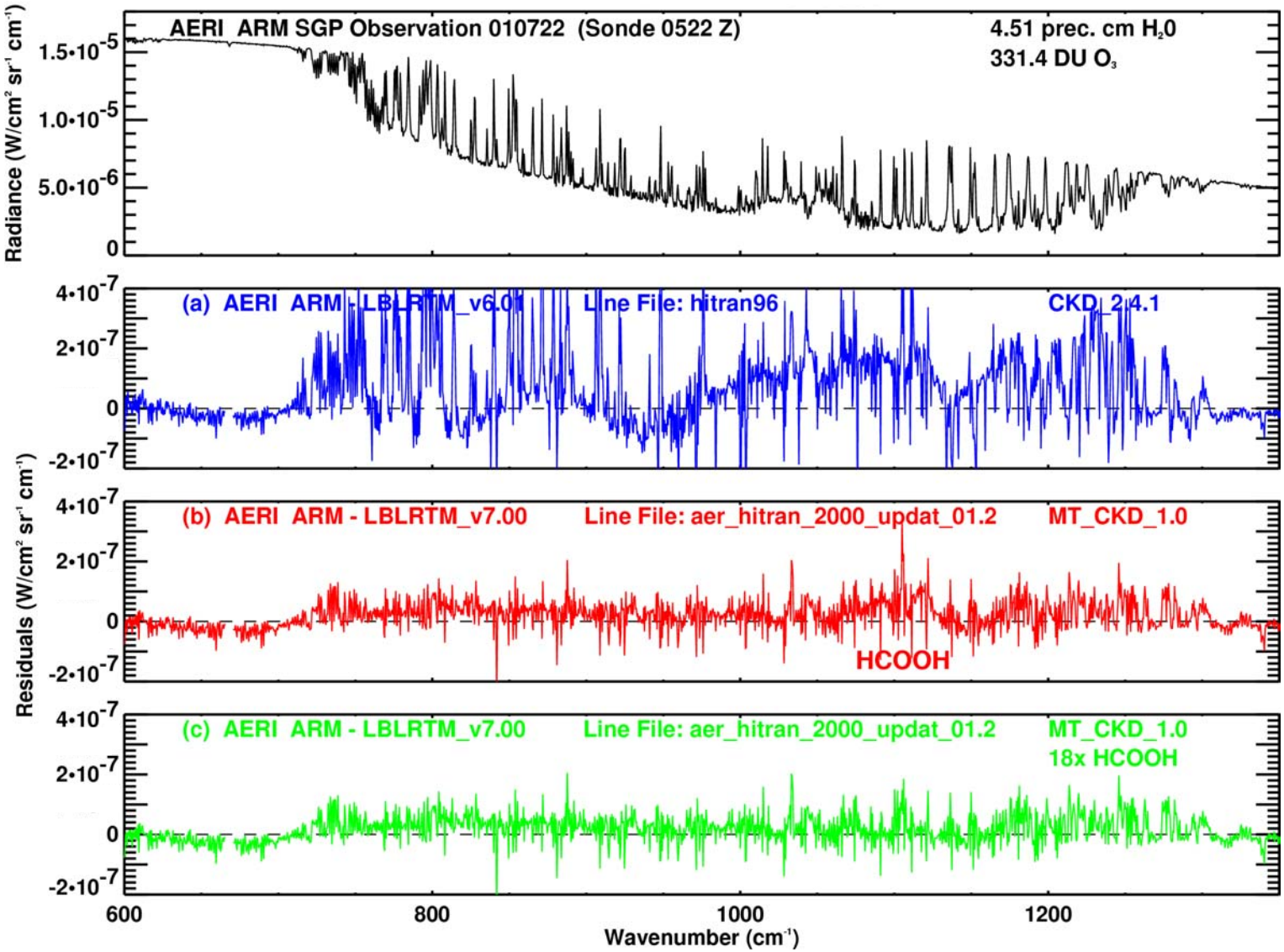
- **Spectral Residuals are Key!**

- **Consistency between bands**
  - **AIRS ν_2 and ν_3 bands to investigate consistency for CO_2**

- **Consistency between species**
  - **TES: temperature from O_3 and H_2O consistent with CO_2 ; N_2O**

- **Consistency between instruments**
  - **SHIS**
  - **AIRS**
  - **TES**
  - **AERI**
  - **ACE**
  - **MIPAS**

AERI Downwelling at the Surface ARM SGP Moist



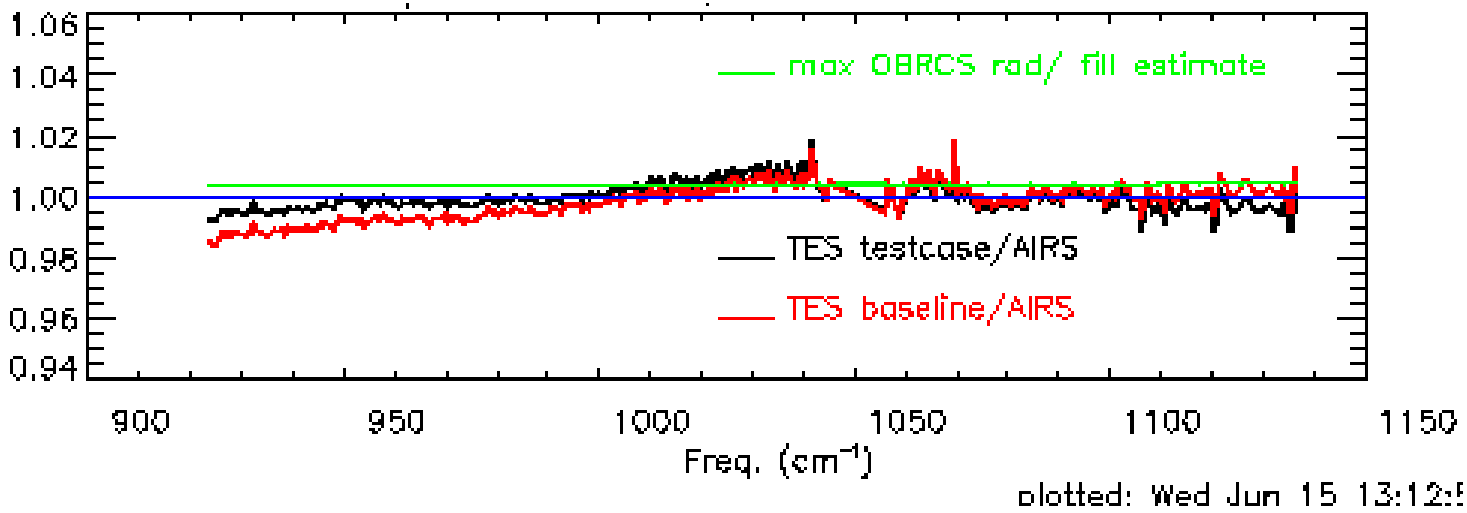
Toth

1%

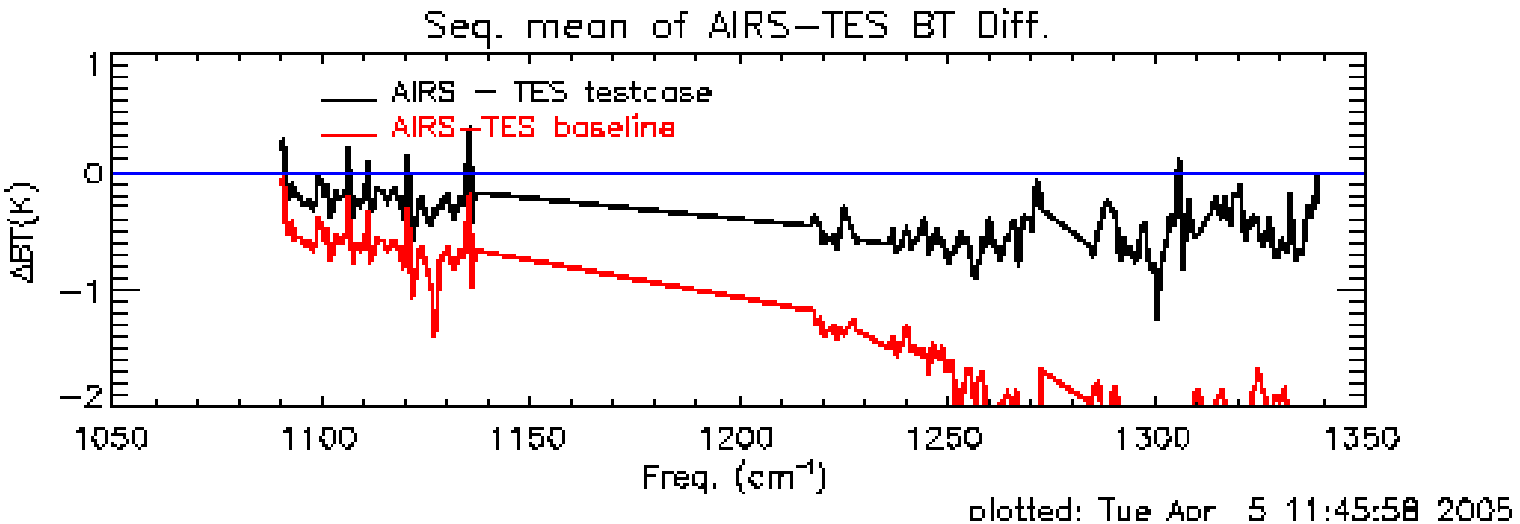
Effect of New Calibration on AIRS - TES Comparisons

Run 2147 - 51 homogeneous nscenes

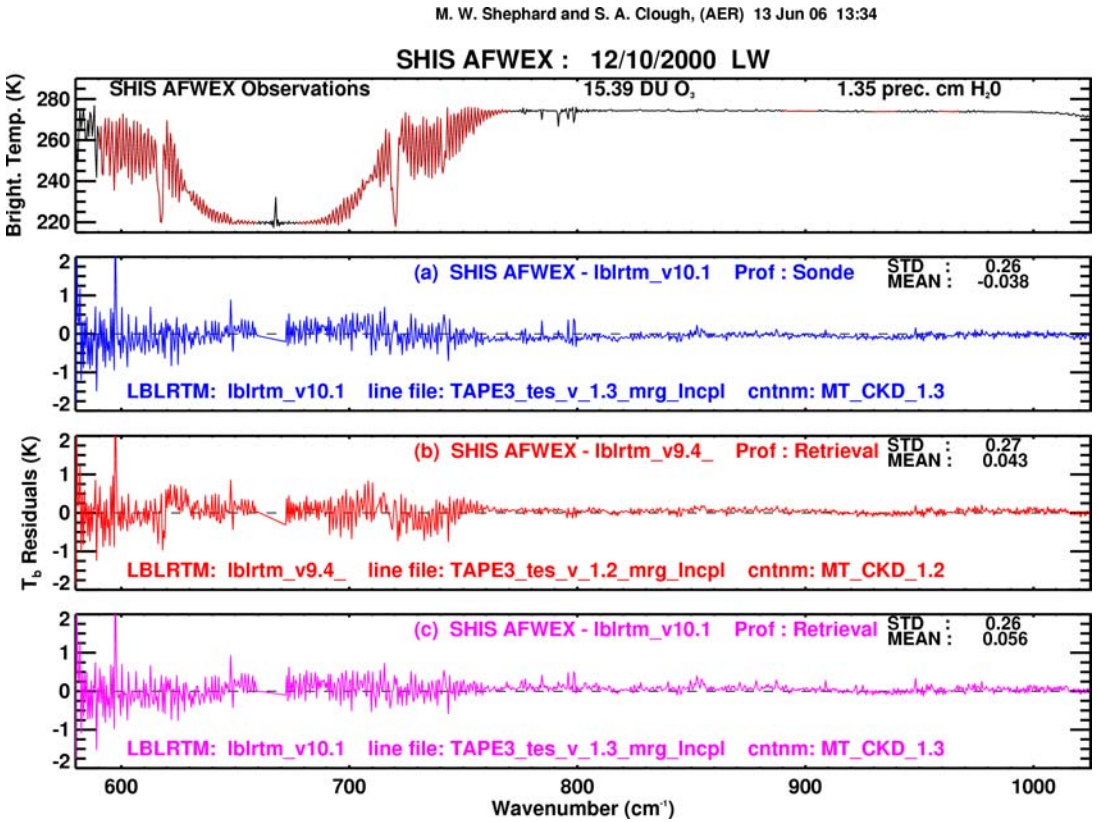
Filter 1B2
TES/AIRS
ozone

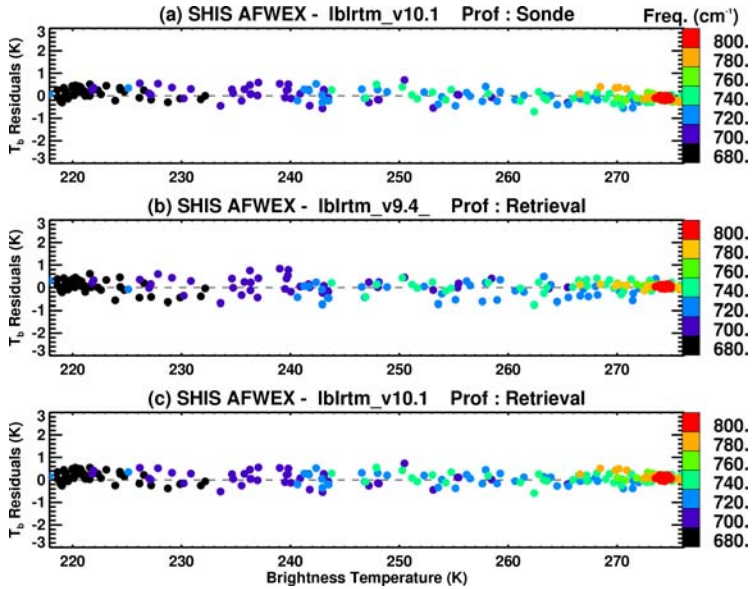


Filter 2A1
AIRS - TES
water, methane

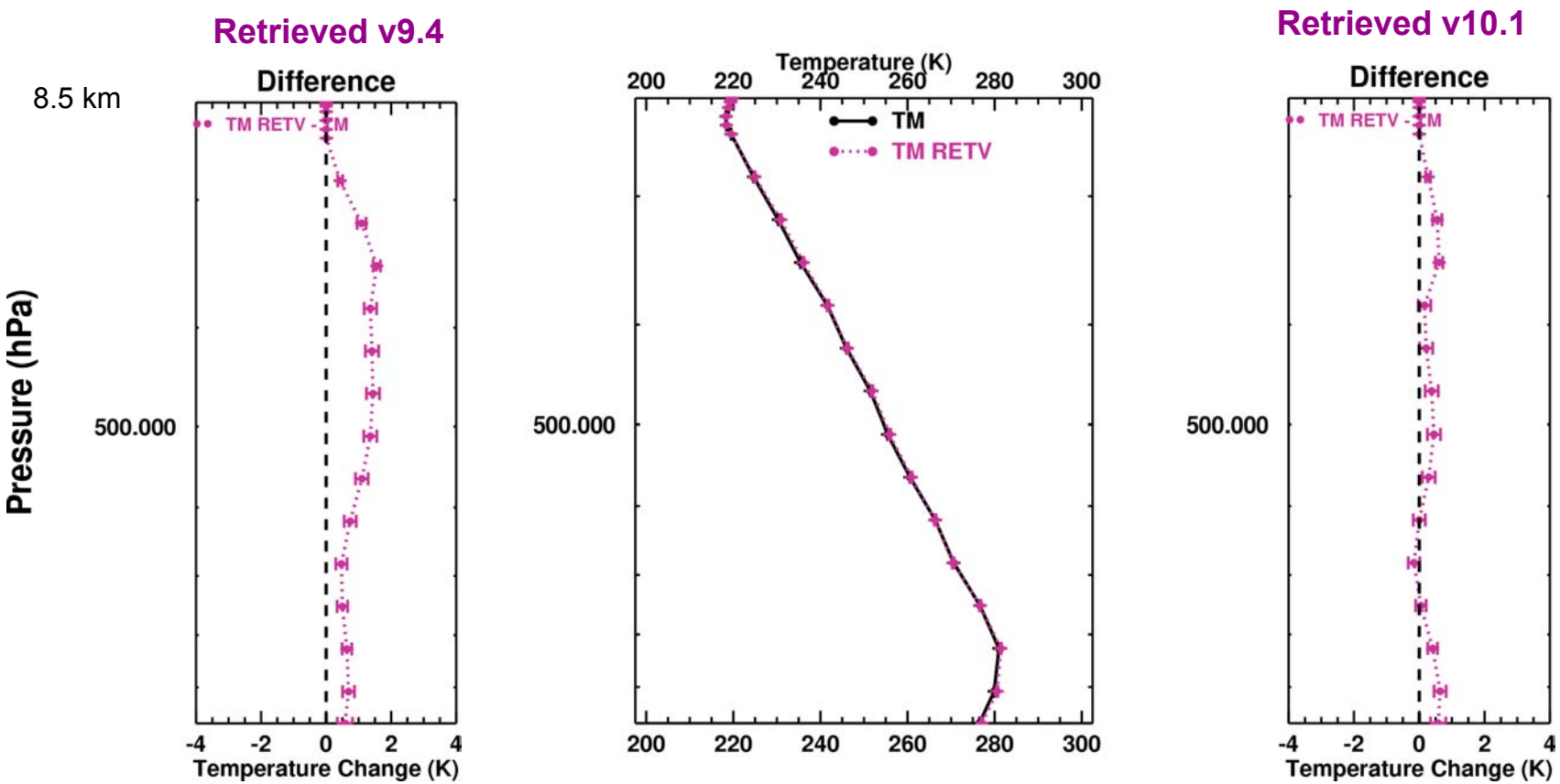


SHIS Analysis from AFWEX Experiment
Oklahoma SGP - sonde

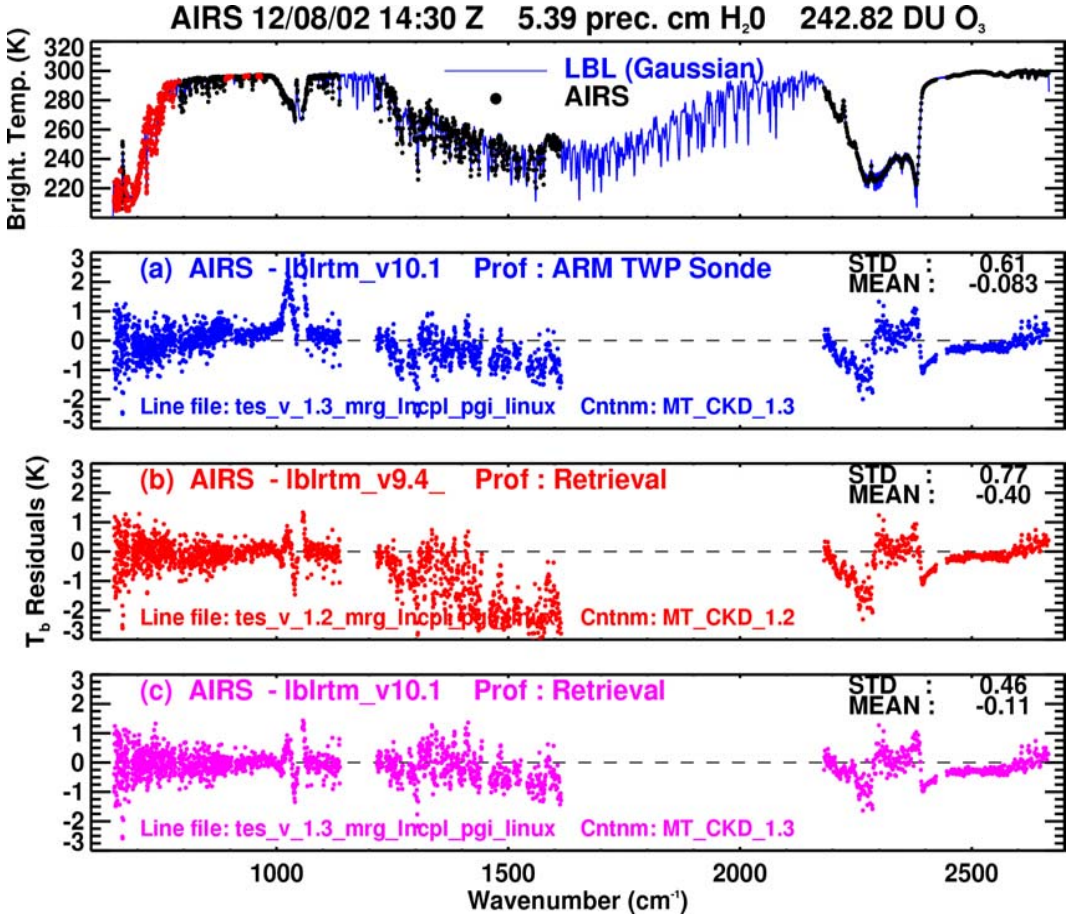


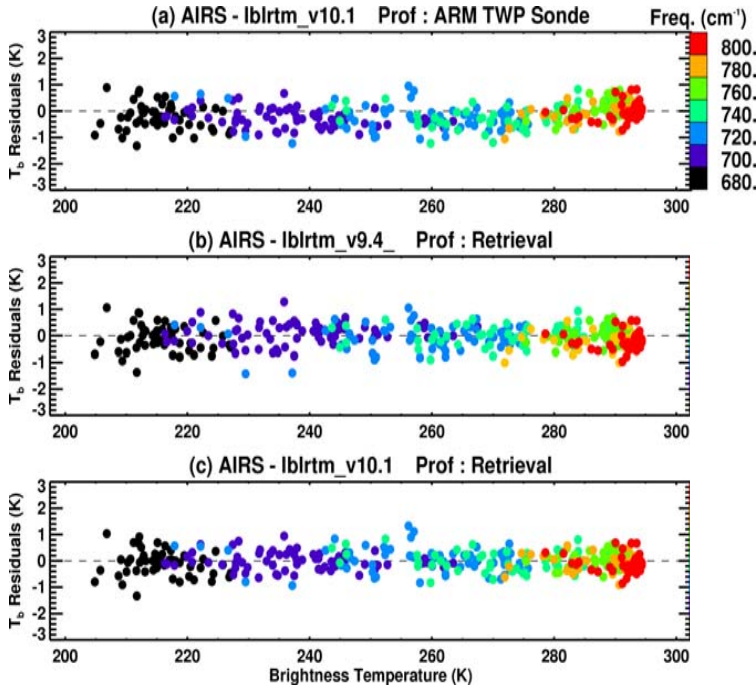


Impact on Temperature Profile
Reference: Radiosonde

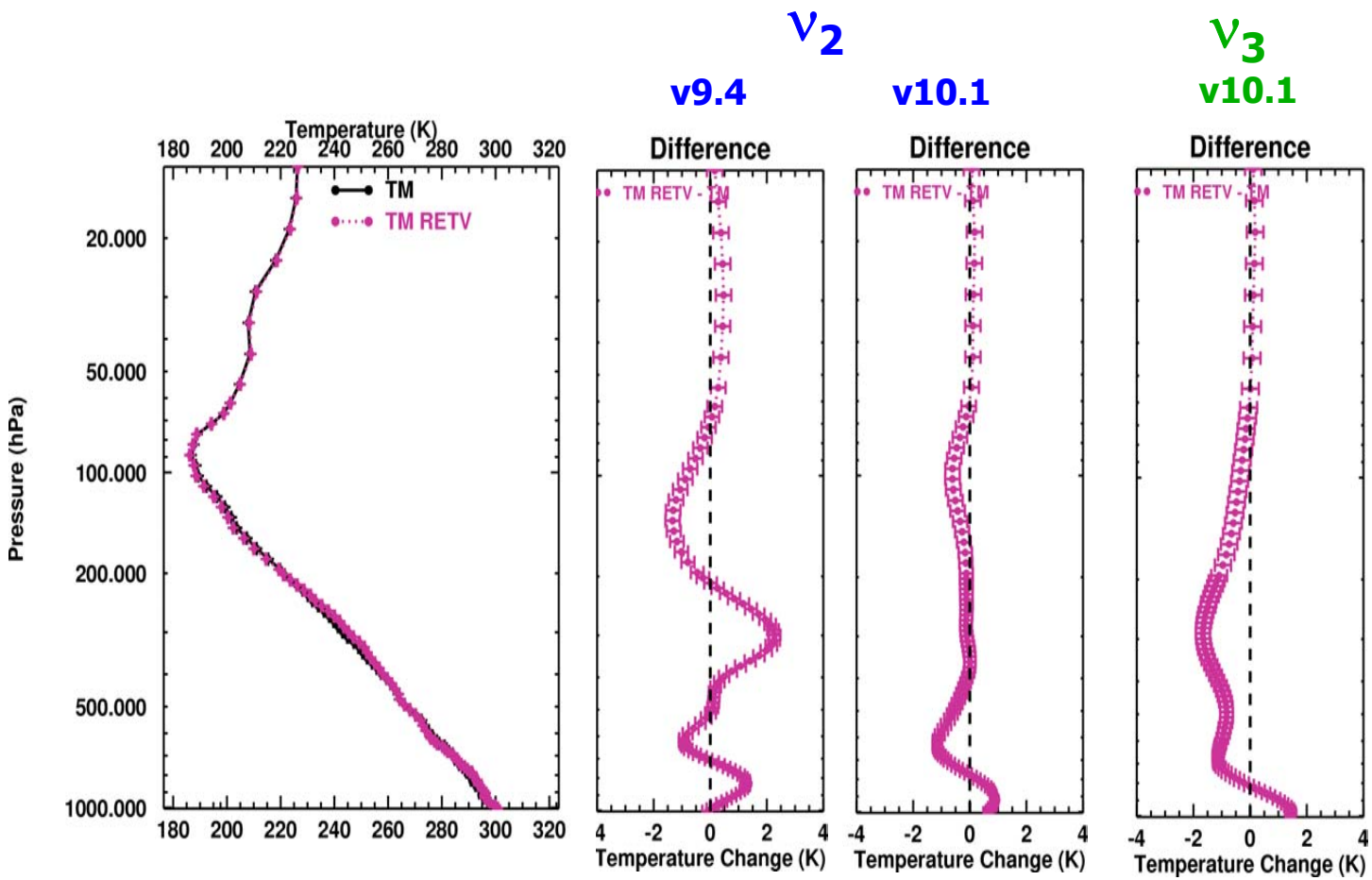


AIRS Analysis
ARM Tropical Western Pacific site - sonde





CO2 Temperature Retrievals

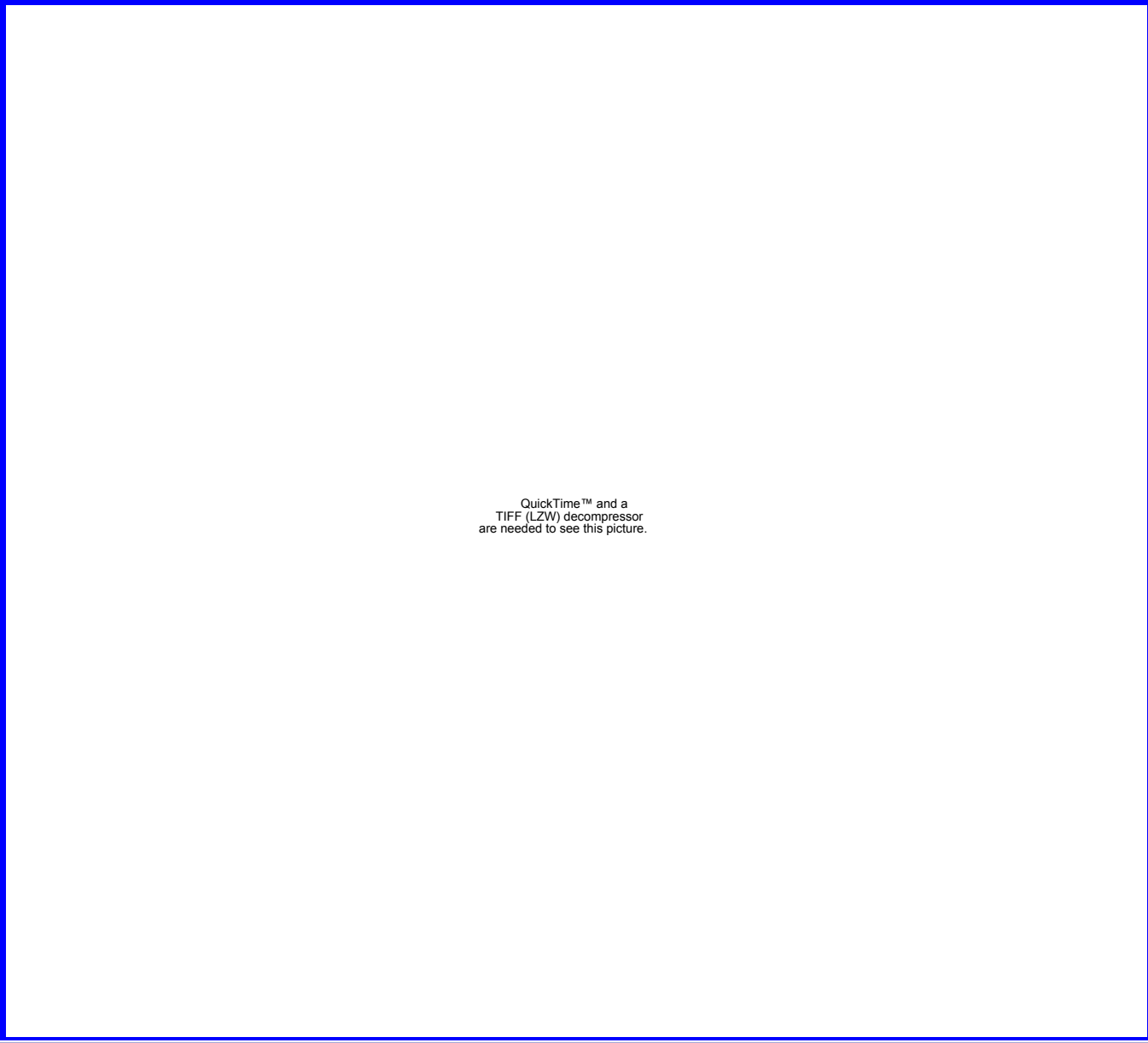


Summary

- Forward Model for Temperature Retrievals significantly improved
  - improvements discussed here: CO_2 ; ν_2; 600 - 800 cm^{-1}
  - P-R line coupling is a key element
  - duration of collision effect and continuum: under study
  - current effort: CO_2 ; ν_3; 2200 - 2400 cm^{-1}
  - 'task force': Strow, Tobin, Shephard, Revercomb and Clough
- Focus of our group is shifting to the validation of
  Water Vapor, Ozone and Clouds
- Issues with water vapor continuum have become remarkably muted
- Updated Code and Line Parameters: to be made public
- Spectral Residuals should play a stronger role in the validation process

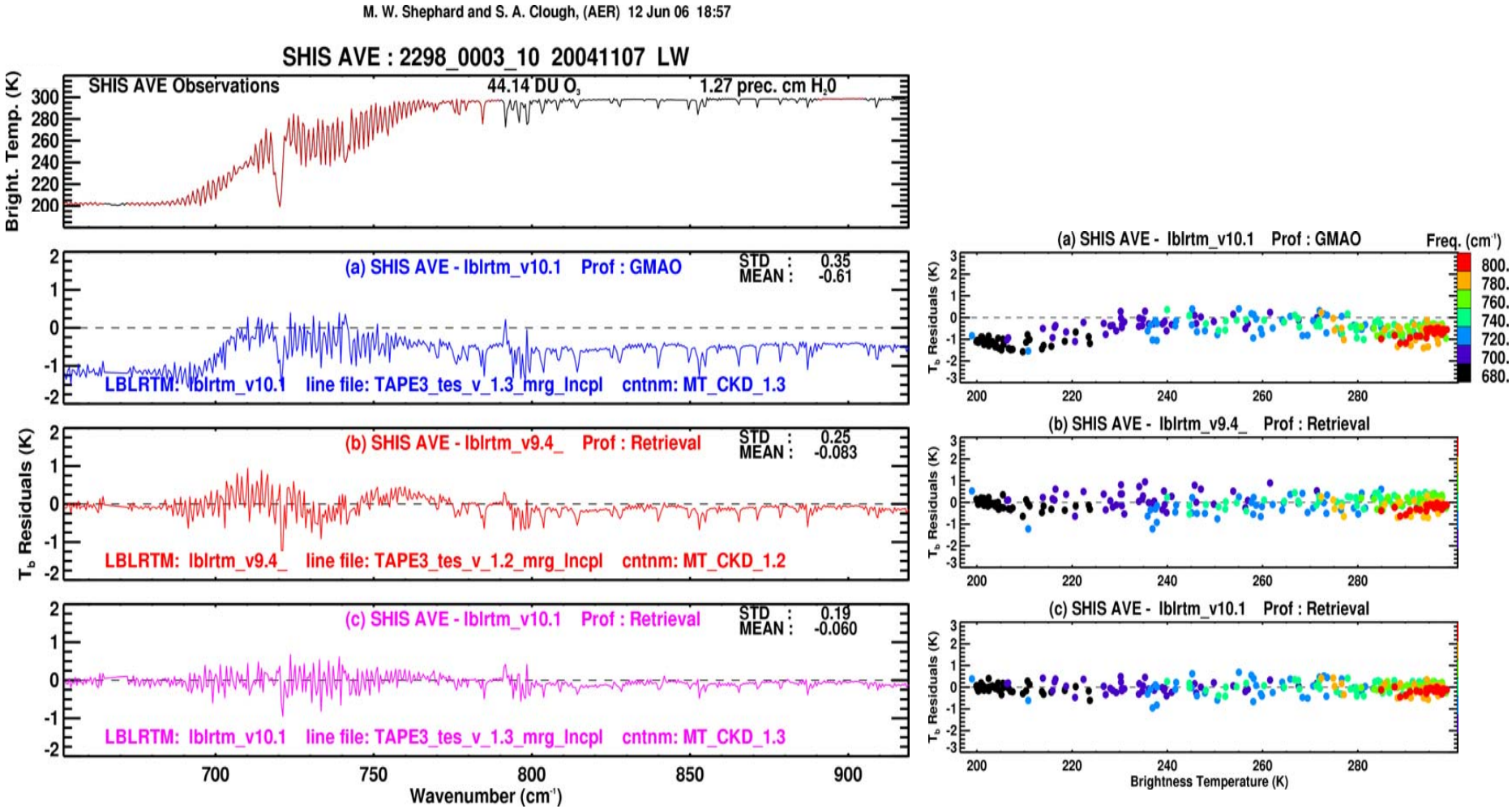
http://rtweb.aer.com/

LBLRTM_v10.3: Analytic Jacobian



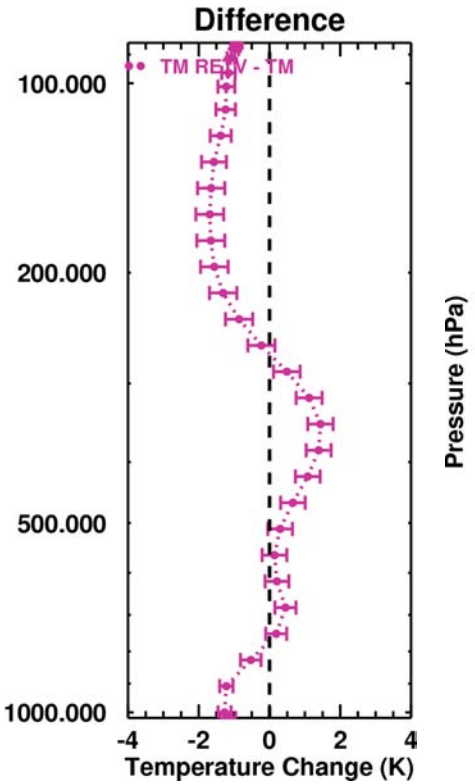
Back-up slides to follow……

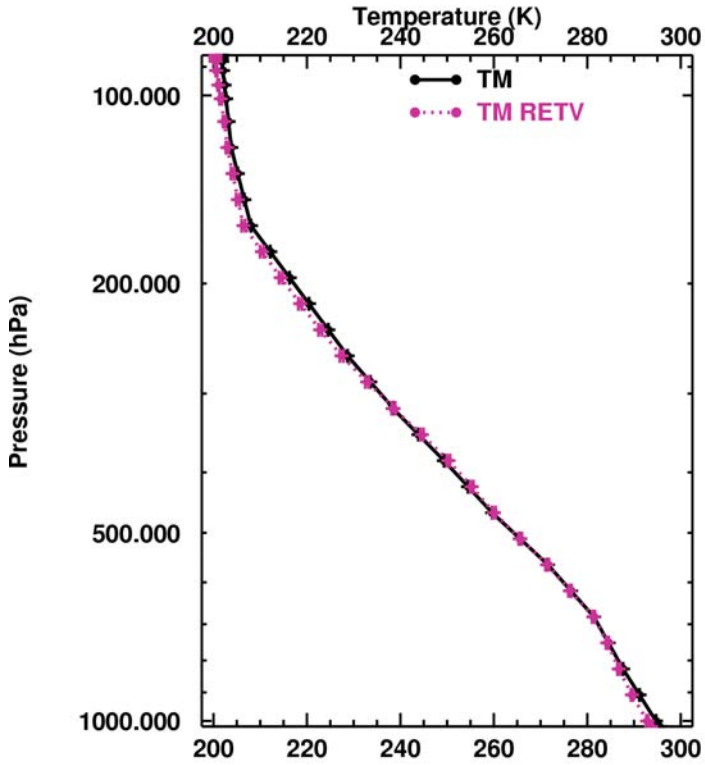
SHIS Analysis from AURA Validation Experiment
Gulf of Mexico - no sonde



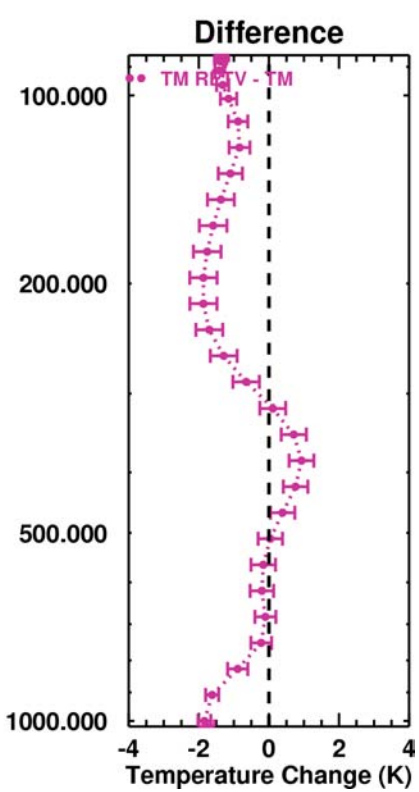
Impact on Temperature Profile
Reference: GMAO

Retrieved v9.4





Retrieved v10.1



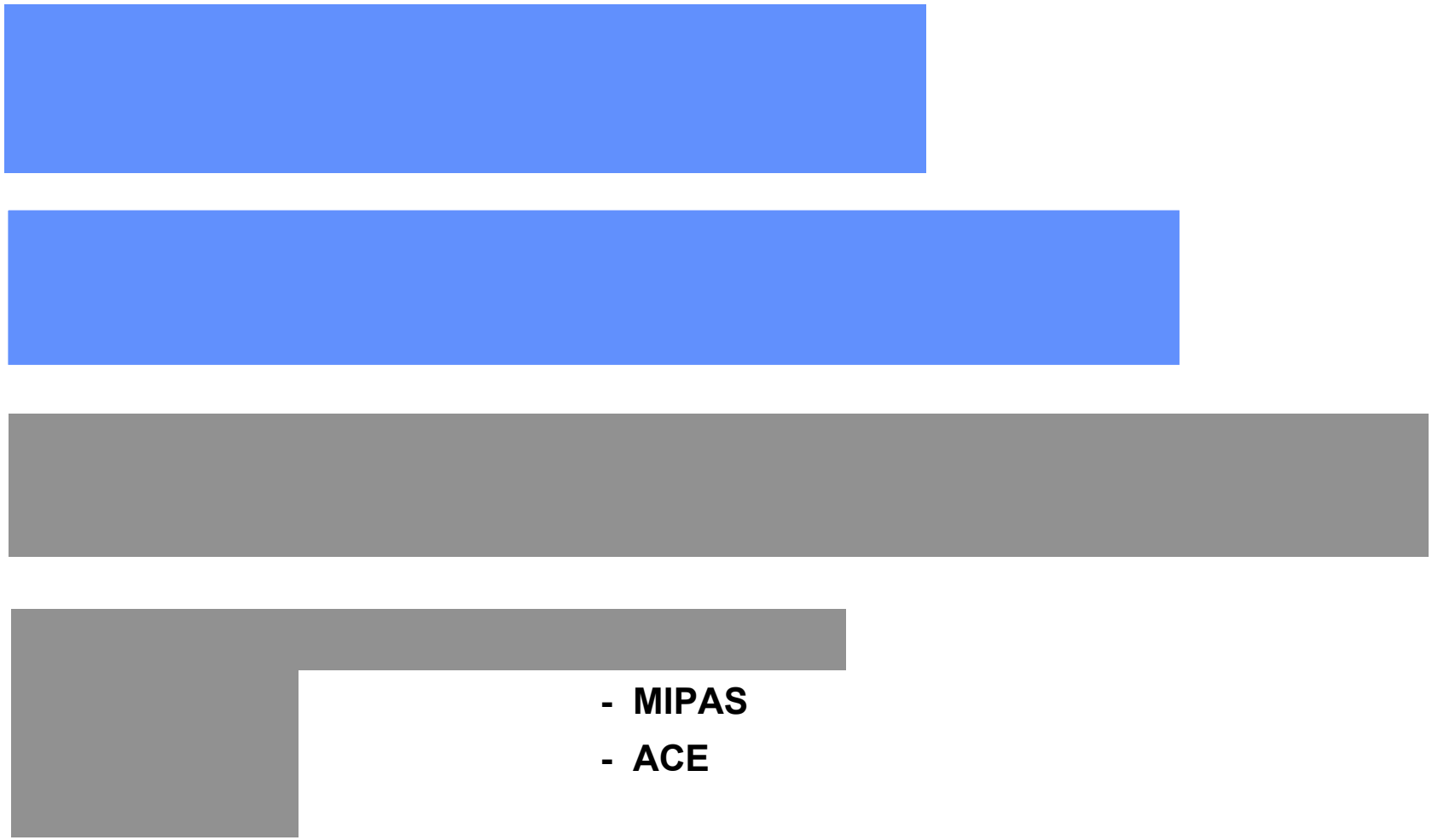
monotonic

General Remarks on CO_2 ν_2 and ν_3

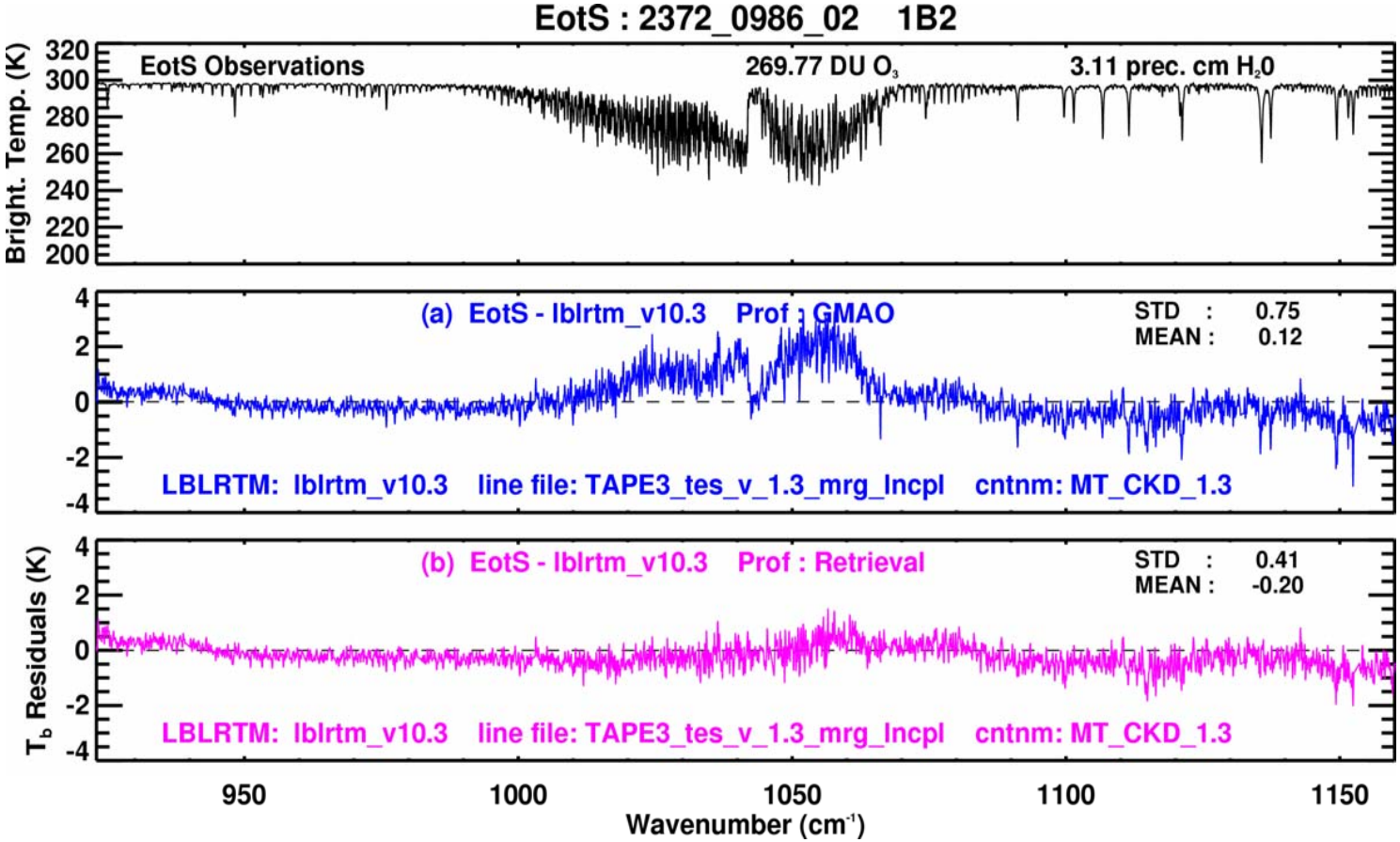
- **P-R line mixing and modest changes in line parameters have been implemented in LBLRTM_v10.1 and tes_v_1.3 line data**
- **The CO_2 ν_2 region shows significantly improved consistency between the CO_2 ν_2 and ν_3 spectral regions, and thus the retrieved temperature profiles from the two regions**
- **However, the consistency between ν_2 and ν_3 is still not satisfactory ….Yet!**
- **Curently working on the CO_2 ν_3 spectral region:**
  - Implement P/R line coupling in the CO_2 v_3 spectral region
  - Further investigate the duration of collision effects and continuum by taking into consideration both CO_2 ν_2 and ν_3

‘Truth’ isn’t ubiquitous- Yet!

- **Spectral Residuals are Key!**



Single TES ARM TWP Residual Comparison

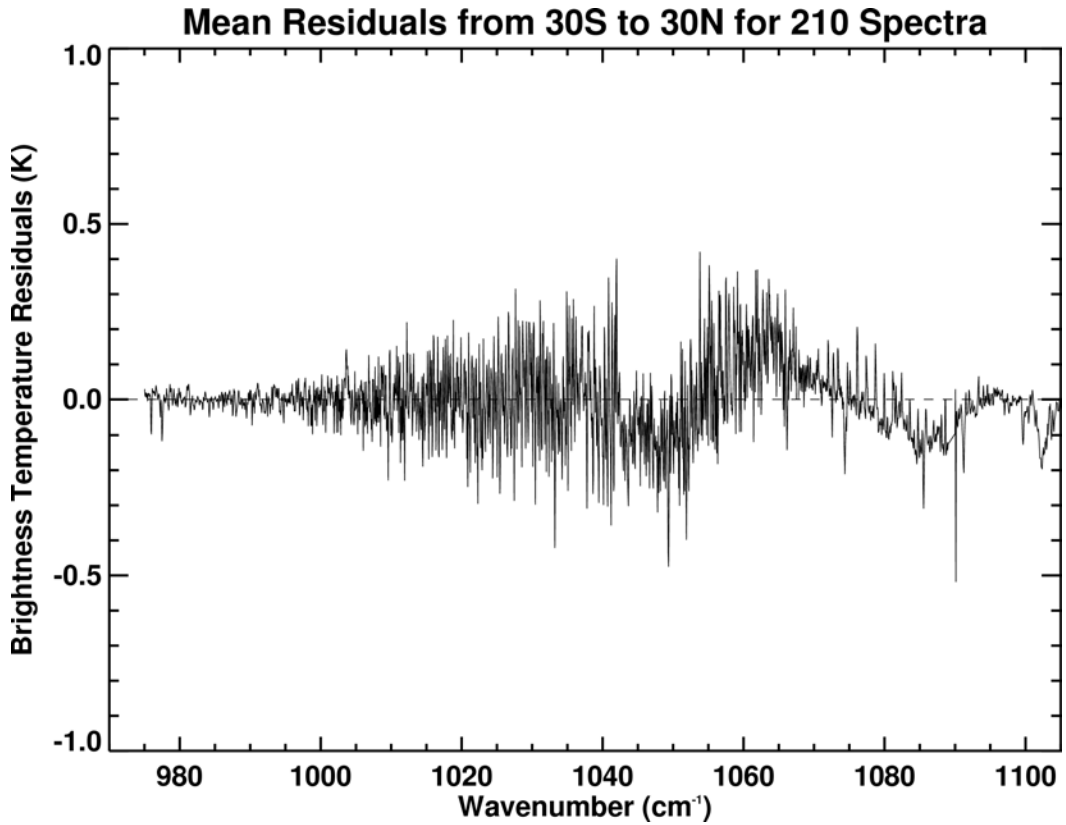


TES Mean Ozone Residuals

Reinhard Beer, JPL

Method

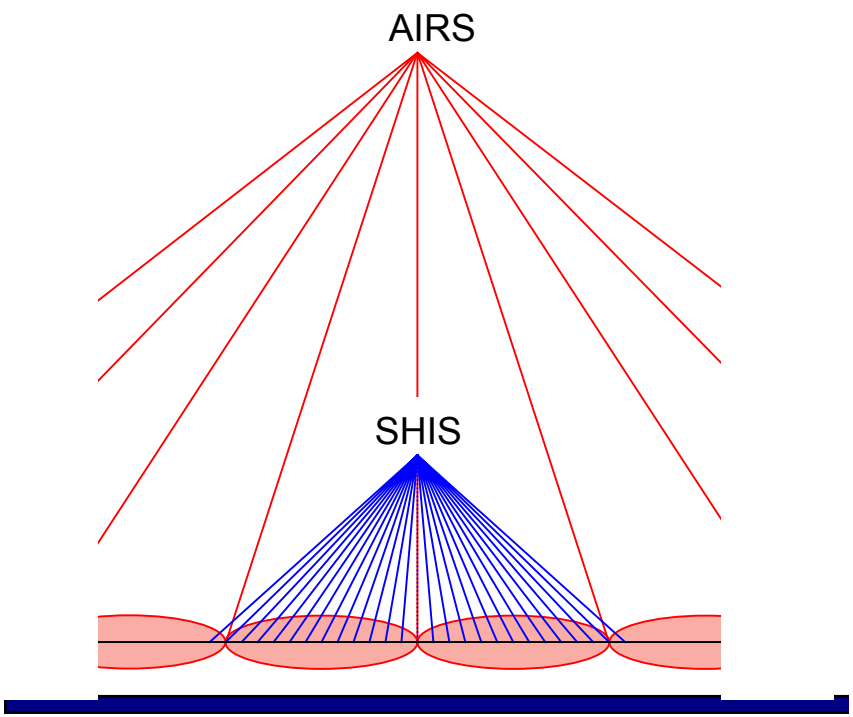
- After T_{ATM}, H_2O, O_3 retrieval step
- Removed data with:
  - CLOUD optical depth > 0.5
  - radiance residual mean > 0.3
  - radiance residual rms > 2.0
  - Latitudes > 30S and 30N
- Mean Residuals (observed – fit) for TES global survey 2147
- Mean of 210 spectra



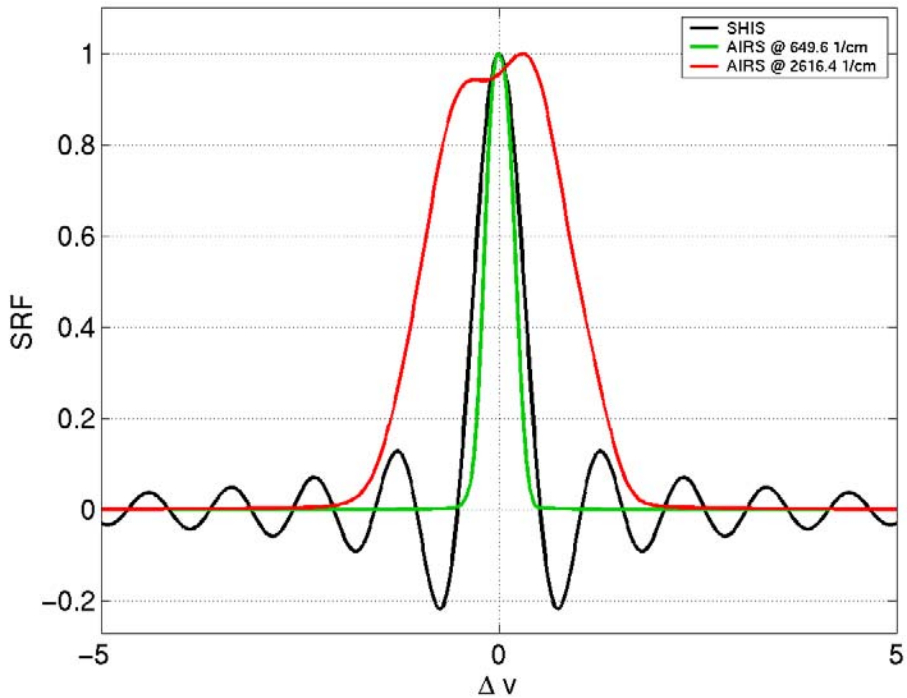
AIRS / SHIS Comparisons

A detailed comparison should account for:

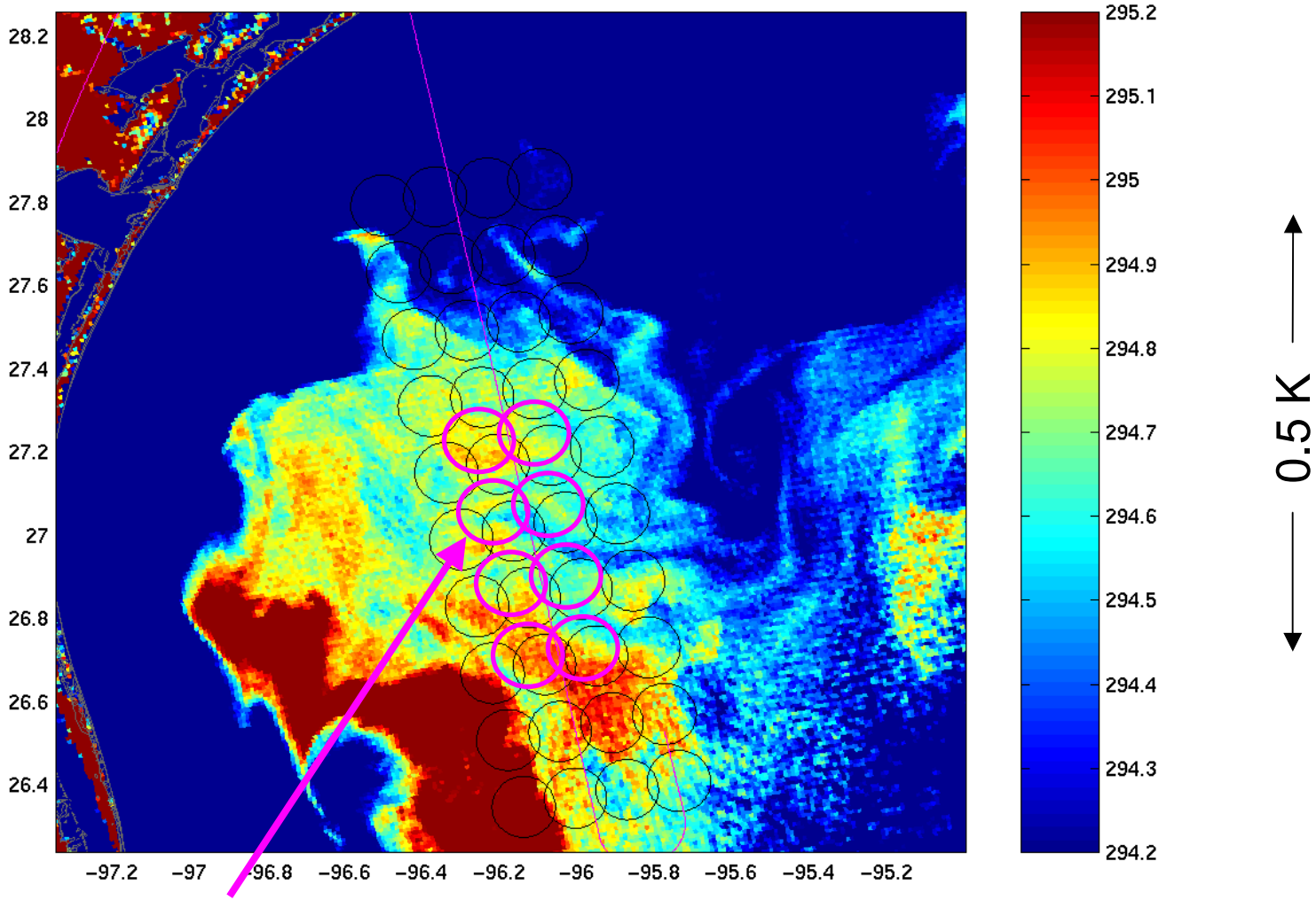
- instrumental noise and scene variations
- Different observation altitudes: **AIRS**: 705km **SHIS:** ~20km
- " view angles ~ nadir ~ ±35deg from nadir
- " spatial footprints ~ 15km at nadir ~ 2km at nadir
- " spectral response $\Delta\nu = \nu/1200$ $\Delta\nu = \sim 0.5\ cm^{-1}$



SHIS and AIRS SRFs



MODIS 12 micron Brightness Temperatures



8 AIRS FOVs used in the following comparisons (near nadir)

448 SHIS FOVs

Comparison Approach

Common Spectral Basis:

- **AIRS: convolve with SHIS Instrument Function (IF)**
- **SHIS: convolve with AIRS Instrument Function**

Common Spatial Basis:

- **Assume a specification of atmospheric state (sonde, ecmwf)**
- **LBL_AIRS**
  - **LBLRTM spectral radiance for each FOV associated with AIRS**
  - **Convolve with AIRS IF, then SHIS IF**
  - **Average over common spatial domain**
- **LBL_SHIS**
  - **LBLRTM spectral radiance for each FOV associated with SHIS**
  - **Convolve with SHIS IF, then AIRS IF**
  - **Average over common spatial domain**

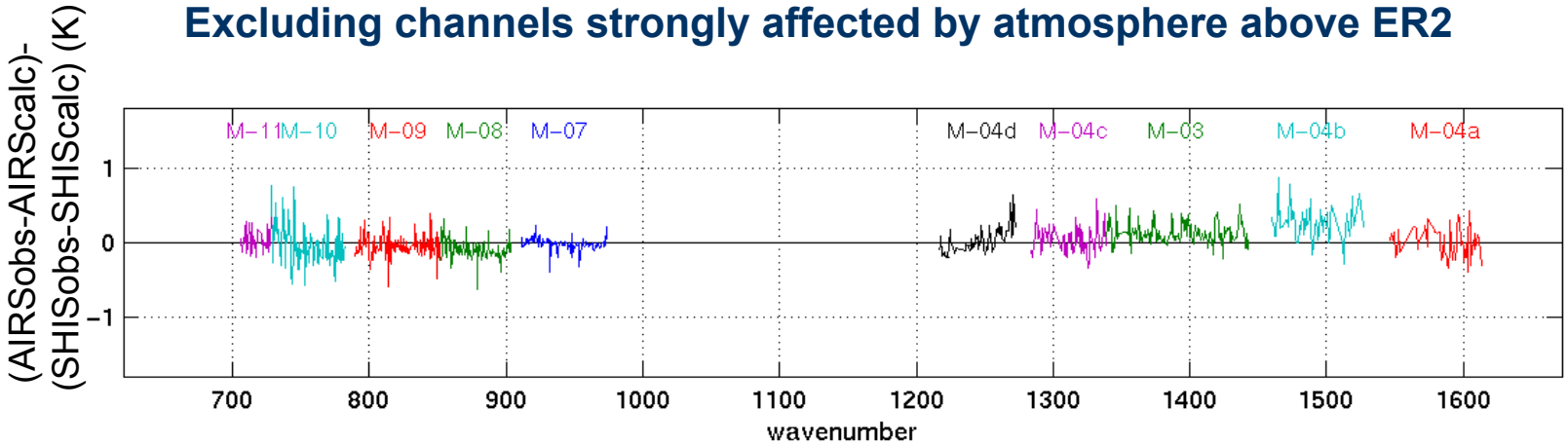
Comparison:

$$\frac{(\text{AIRS} - \text{LBL\_AIRS}) - (\text{SHIS} - \text{LBL\_SHIS})}{\{\text{AIRS} - \text{SHIS}\} - [\text{LBL\_AIRS} - \text{LBL\_SHIS}]}$$

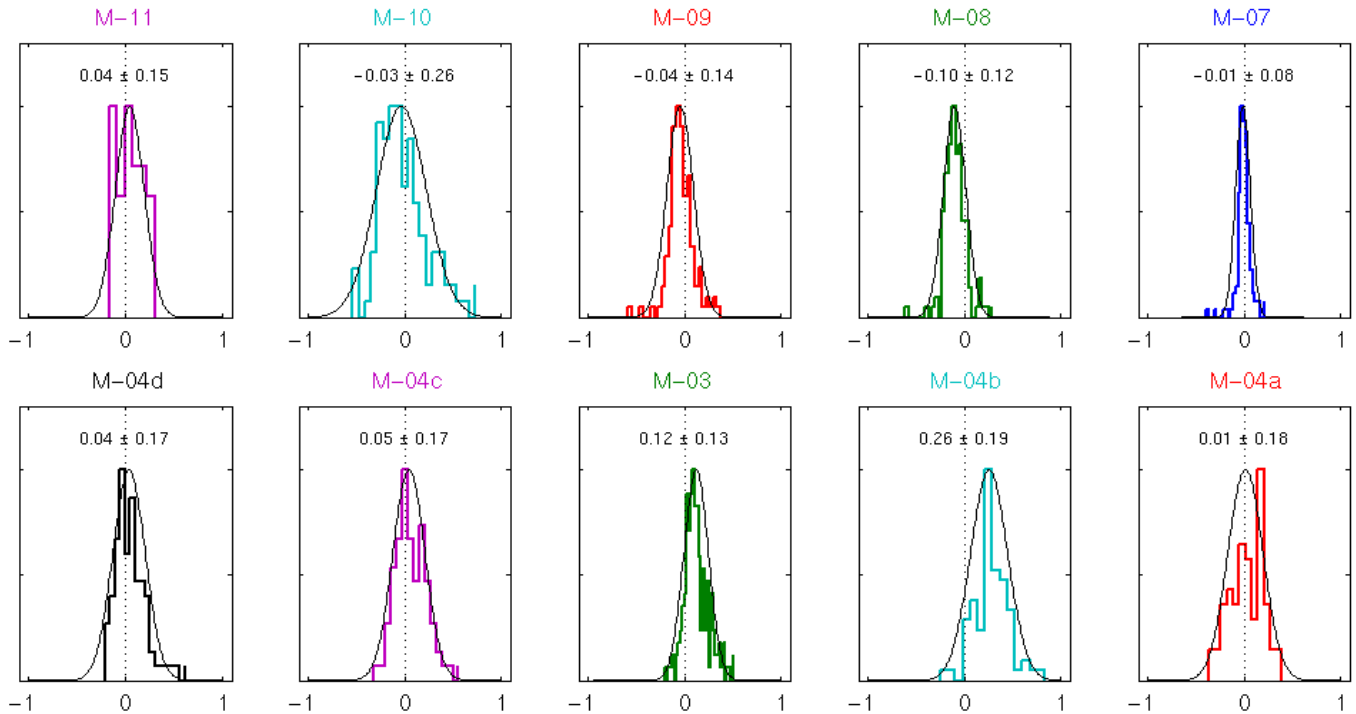
small

AIRS / SHIS Brightness Temperature Comparison

Excluding channels strongly affected by atmosphere above ER2

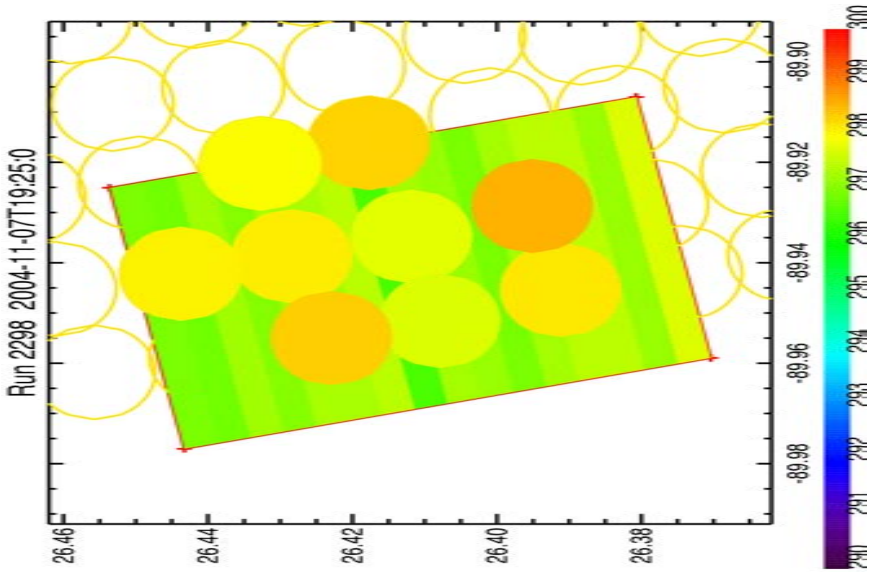


Histograms



Aura Validation Experiment: Nov. 7, 2004 : Gulf of Mexico

AVE Observations to Investigate Line-by-line Calculations



Brightness Temperature (K) @ 1105 cm $^{-1}$

SHIS scans - averaged nine ~2 km circles

TES nadir scan - average of the sixteen 0.5 x 5km rectangular pixels from overpass

SHIS : ~ 2 km

Spectral resolution: 0.48 cm^{-1}

TES Underflight

Altitude of 18 km

TES : 8 x 5 km

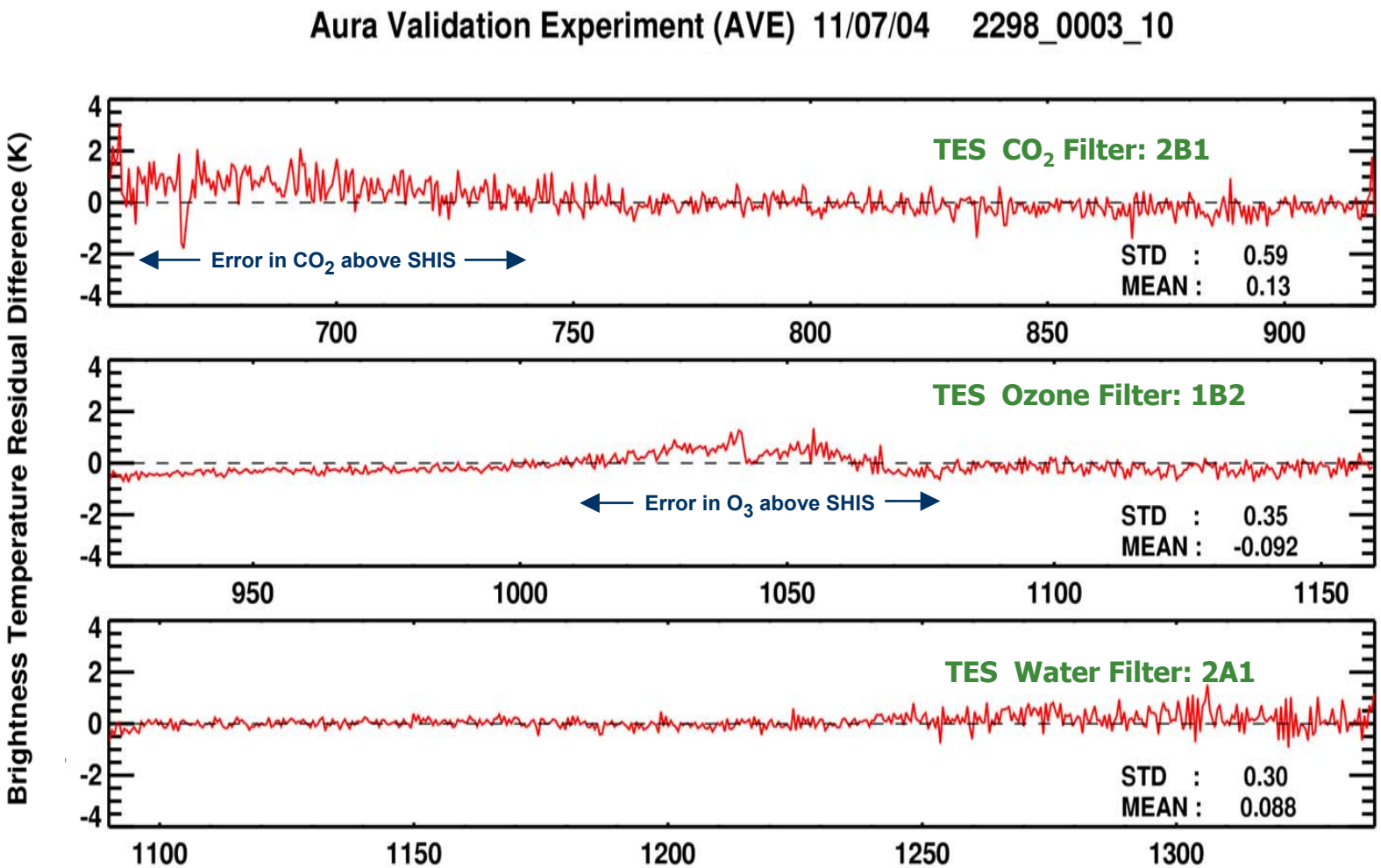
Spectral resolution: 0.06 cm^{-1}

Nadir

19:25 UTC

TES - SHIS Radiance Comparison

- **TES Convolved to SHIS ILS**
- **{TES - LBLRTM(TES Geometry)} - {SHIS - LBLRTM(SHIS Geometry)}**



Role of Spectrscopy

- **Remote Sensing** (infrared)
  - High Resolution Spectral Radiances
  - Upwelling/Downwelling

- **Specification of the Atmosphere** (microwave)
  - Atmospheric Water Vapor Column
  - Water Vapor Continuum

- **Atmospheric Fluxes and Cooling Rates**

Line Parameters

- HITRAN: reference source for 'AER' Line Parameters
- Substitutions are only made for very specific reasons and only with extensive validation
- aer_v_1.0 (0 -122,656 cm-1)
- tes_v_1.3 (500 - 3500 cm-1)

1. Water Vapor
   - HITRAN 2000 + Update 1.1 (Toth et al.)
2. Carbon Dioxide
   - HITRAN 2000
   - Line Coupling (Hartmann et al.)
3. Ozone
   - MIPAS (Wagner at al.; Flaud et al.)

Continuum: MT_CKD_1.3

- **Water Vapor**
  - Self / Foreign
  - Single Line Shape for each
- **Carbon Dioxide**
  - ν_2 Region Scaled based on this study
  - Continuing Research Focus
- **Nitrogen: Collision Induced**
  - 2330 cm-1 Region
  - Lafferty et al., 1996
- **Oxygen: Collision Induced**
  - 1600 cm-1 Region
  - Thibault et al., 1996

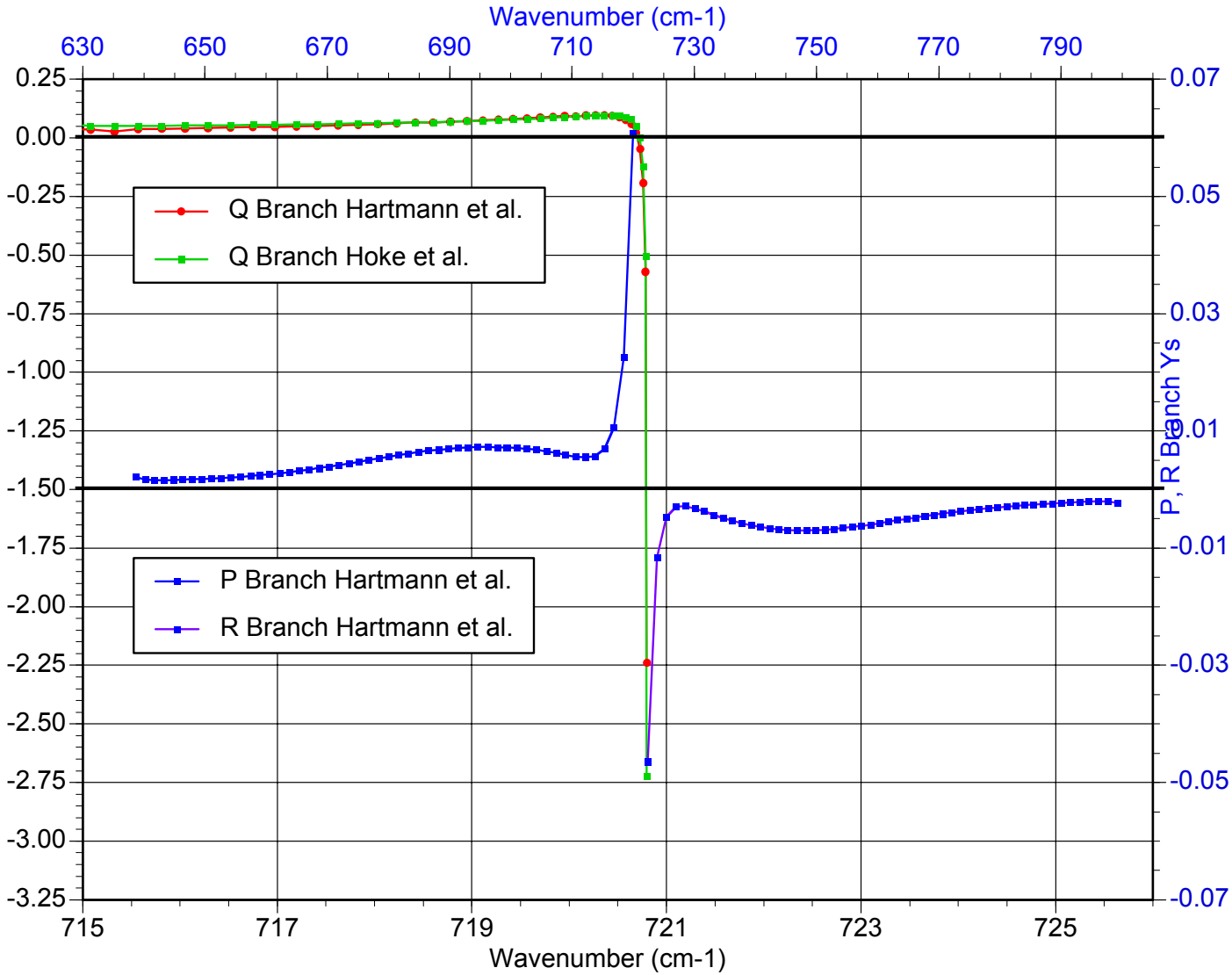
Line Coupling

Lorentz

$$k_i(\nu) = \frac{1}{\pi} \frac{S_i}{(\nu - \nu_i)^2 + \alpha_i^2} \left[1 + y_i(\nu - \nu_i)\right]$$

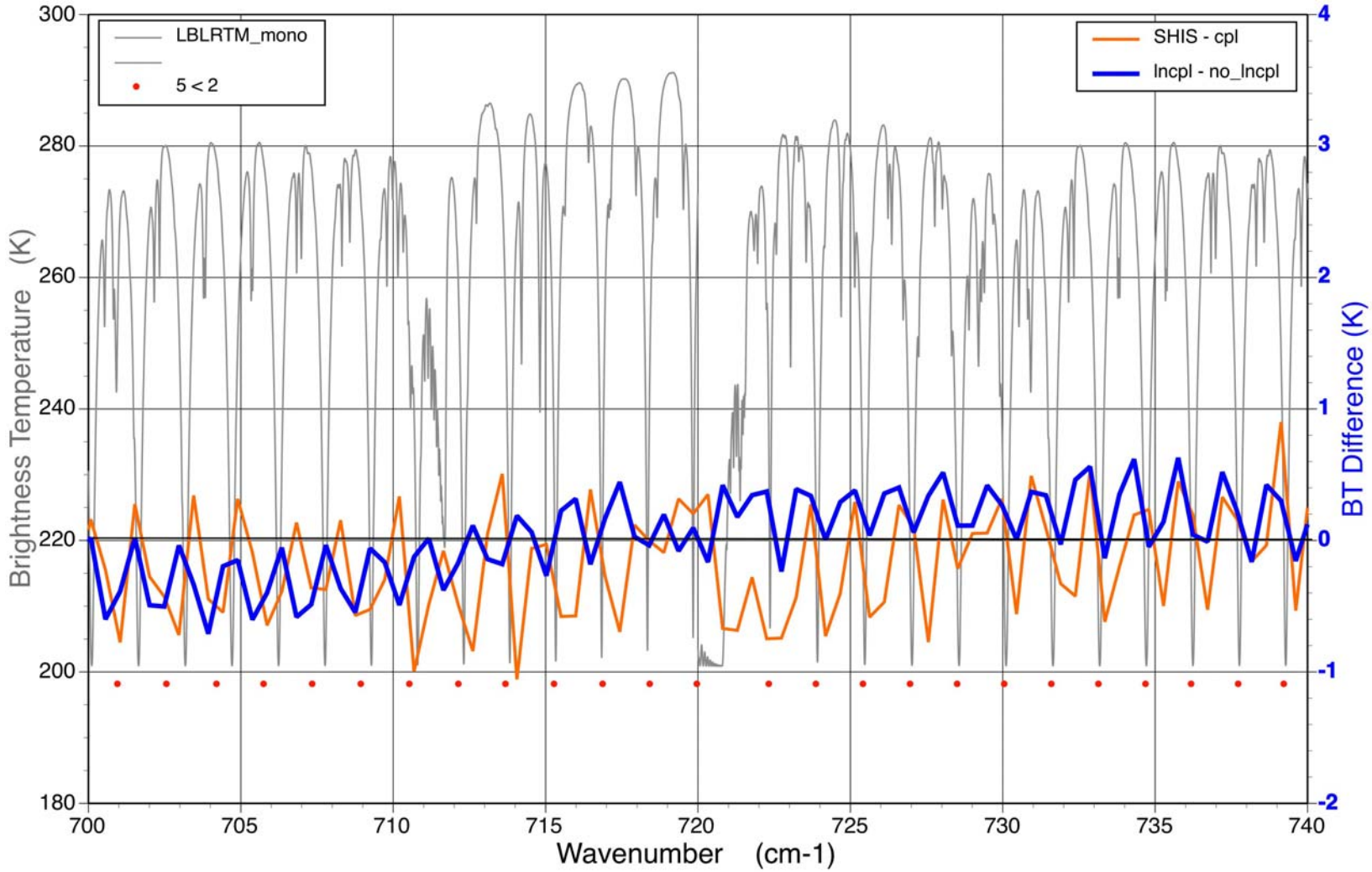
y_i: line coupling coefficient

Line Coupling Parameters for the 5 < 2 Band



Effect of P-R Line Coupling on S-HIS Residuals

(Hartmann et al. Parameters)



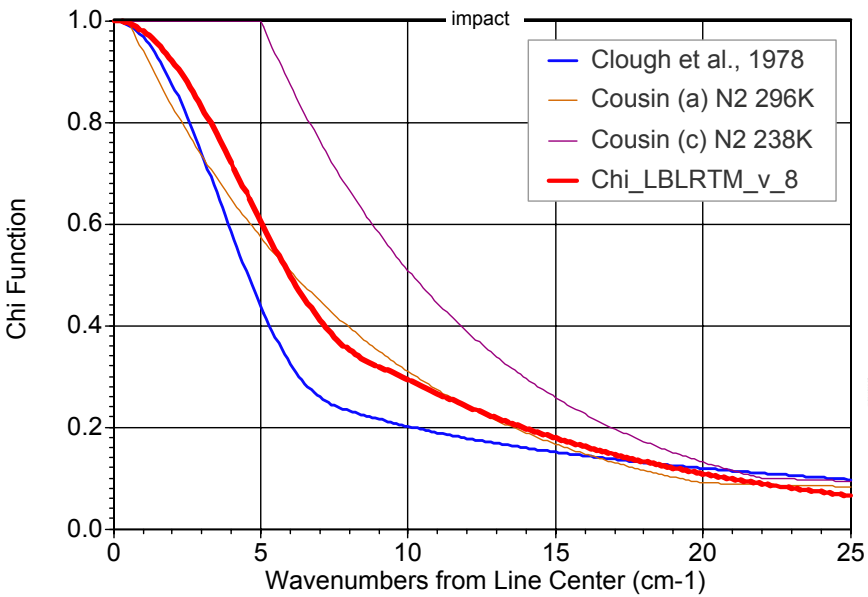
Duration of Collision Effects

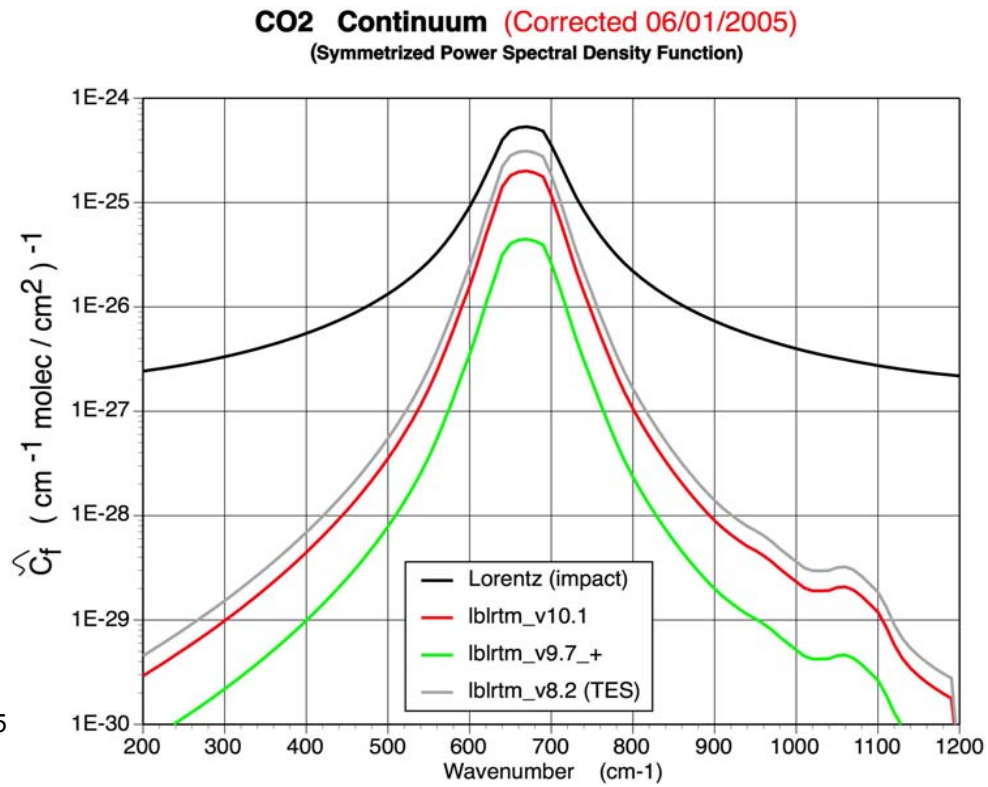
Lorentz

$$k_i(\nu) = \frac{1}{\pi} \frac{S_i}{(\nu - \nu_i)^2 + \alpha_i^2} \qquad \left[\chi(\nu - \nu_i)\right]$$

χ_i: duration of collision

CO_2 Line Shape





Chi function: Multiplies Lorentz function to account for duration of collision effects.

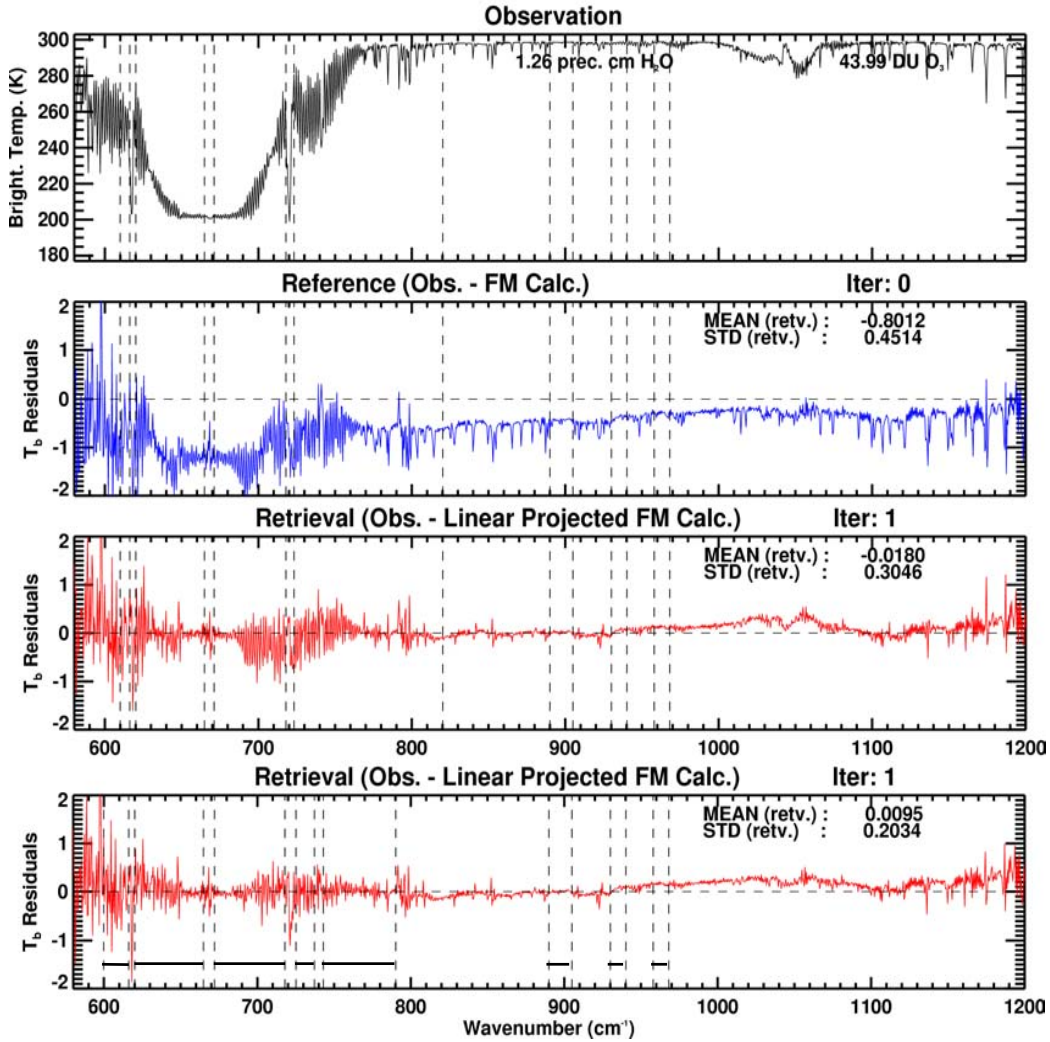
Continuum: Line contributions 25 cm^{-1} beyond line center

SHIS AVE Retrieval Results

GMAO

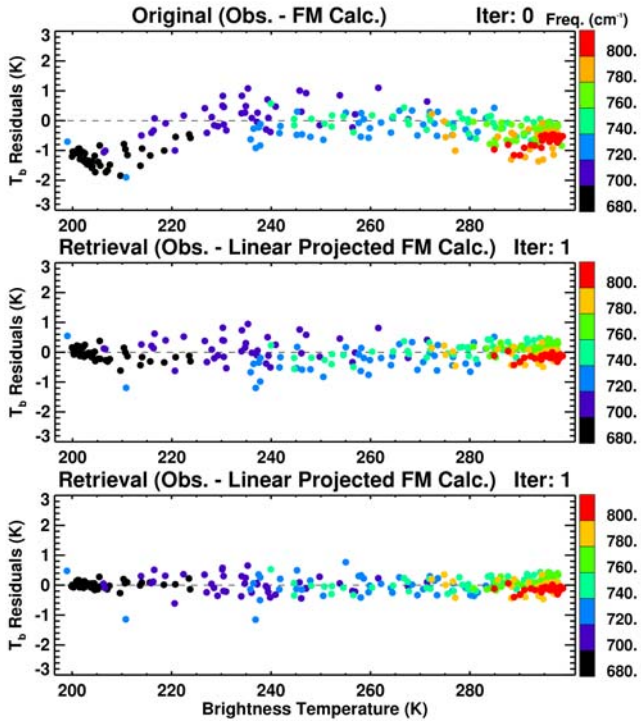
Temp & Spectroscopy

Temp Only

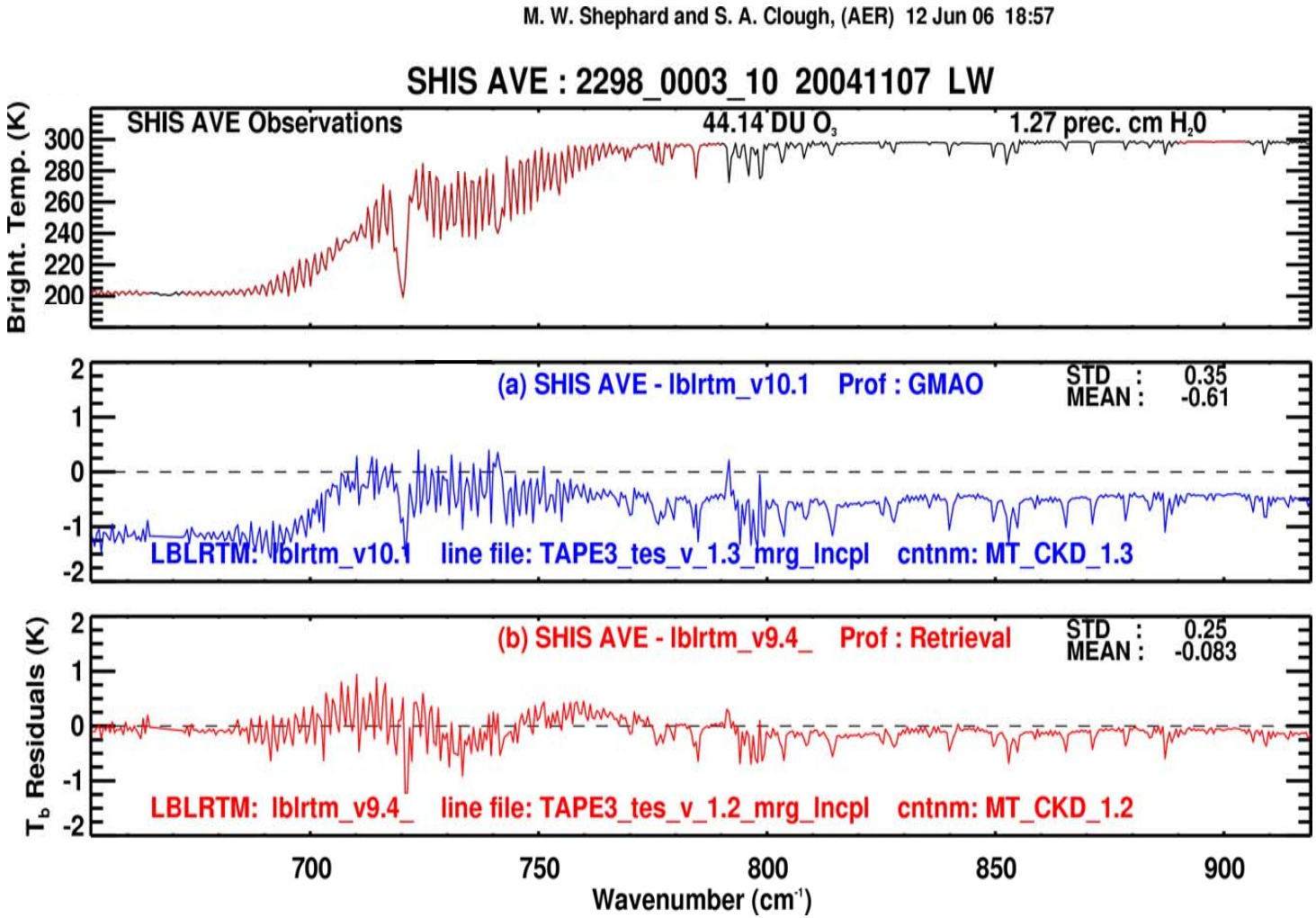


Retrieval Spectral Region

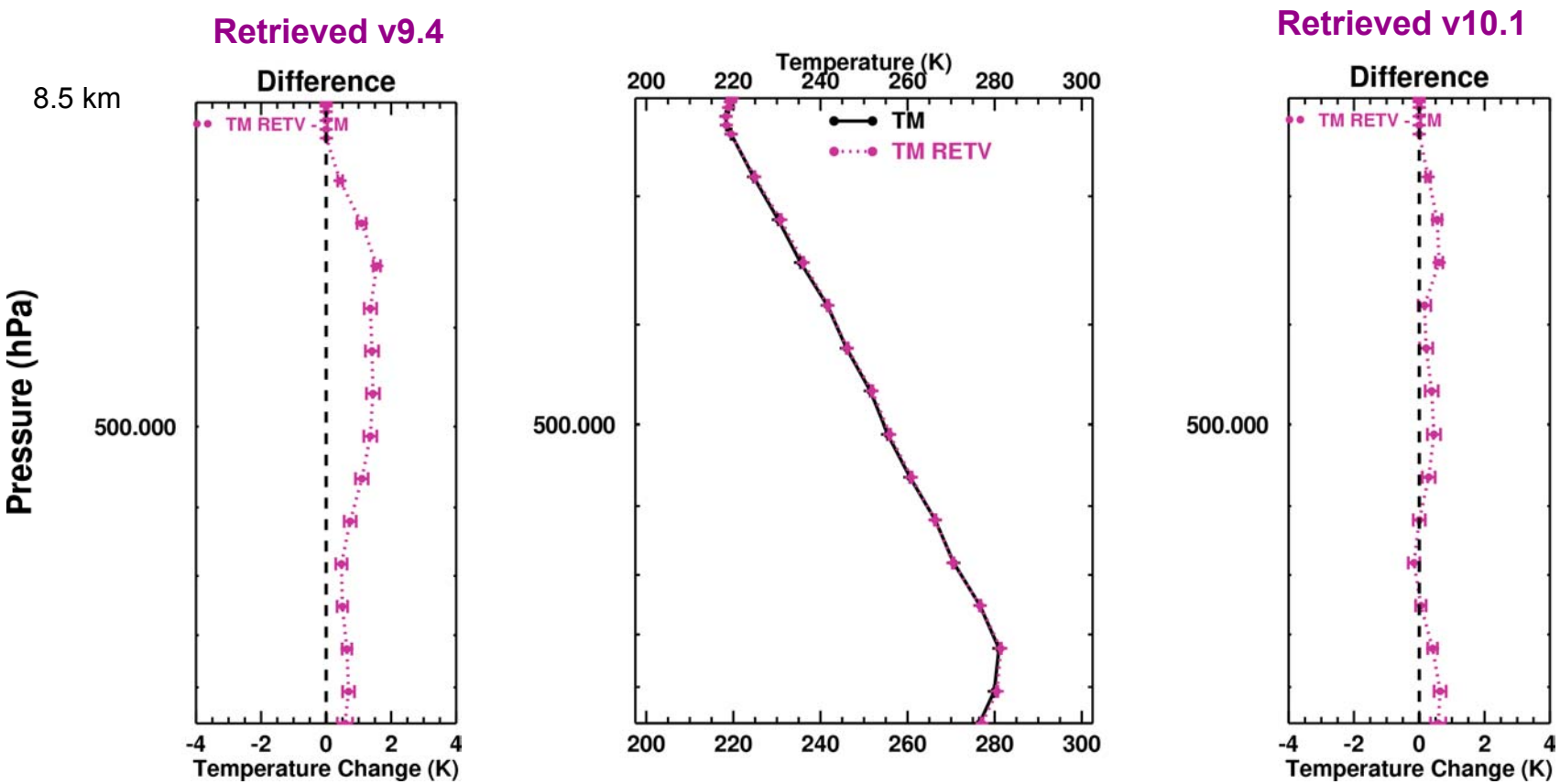
Scatter plots of Brightness Temperature vs. Residuals (Obs - Calc.) binned in 20 cm^{-1} intervals from the CO_2 v_2 region



SHIS Analysis from AURA Validation Experiment
Persistent Spectral Residuals

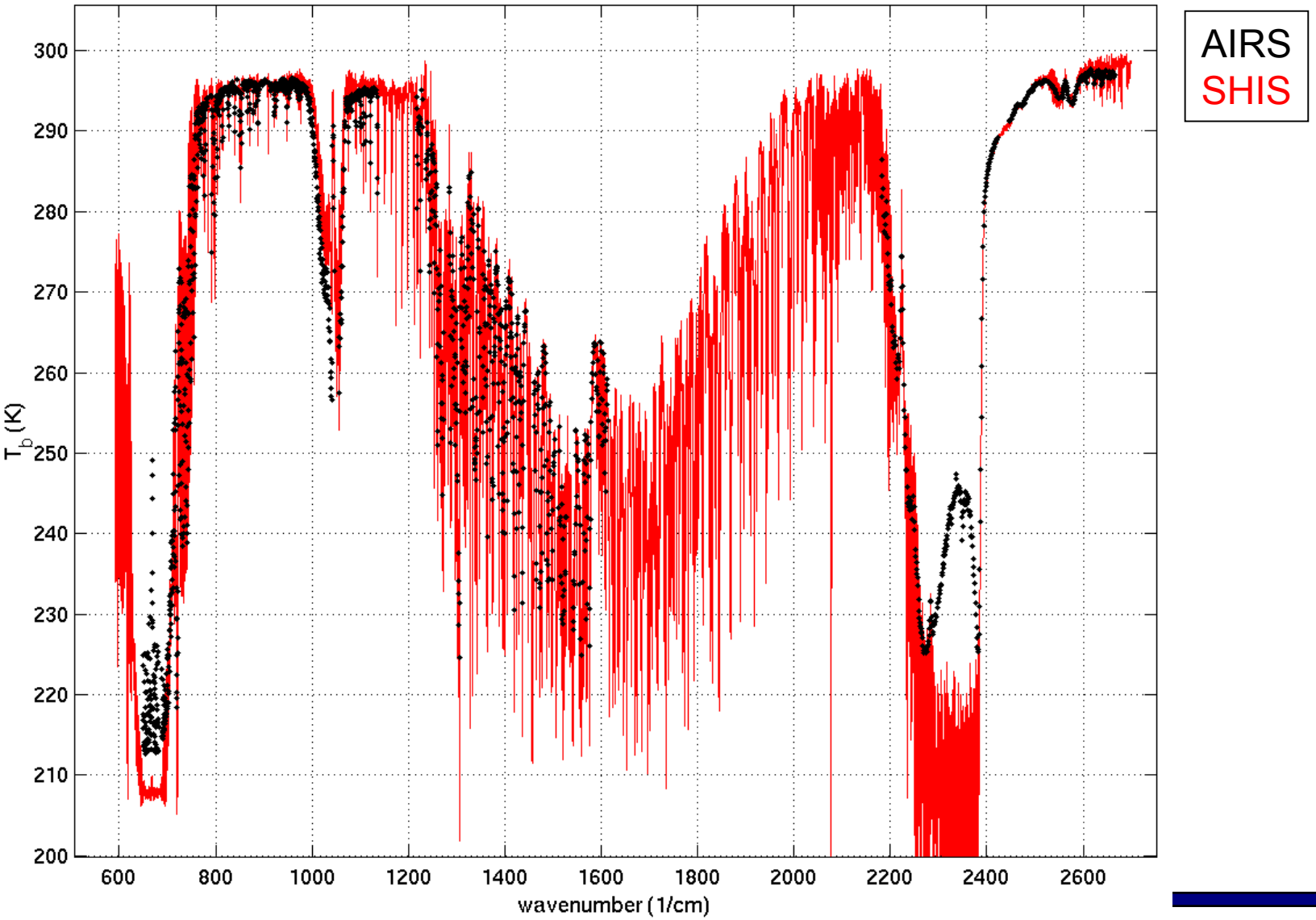


Impact on Temperature Profile
Reference: Radiosonde



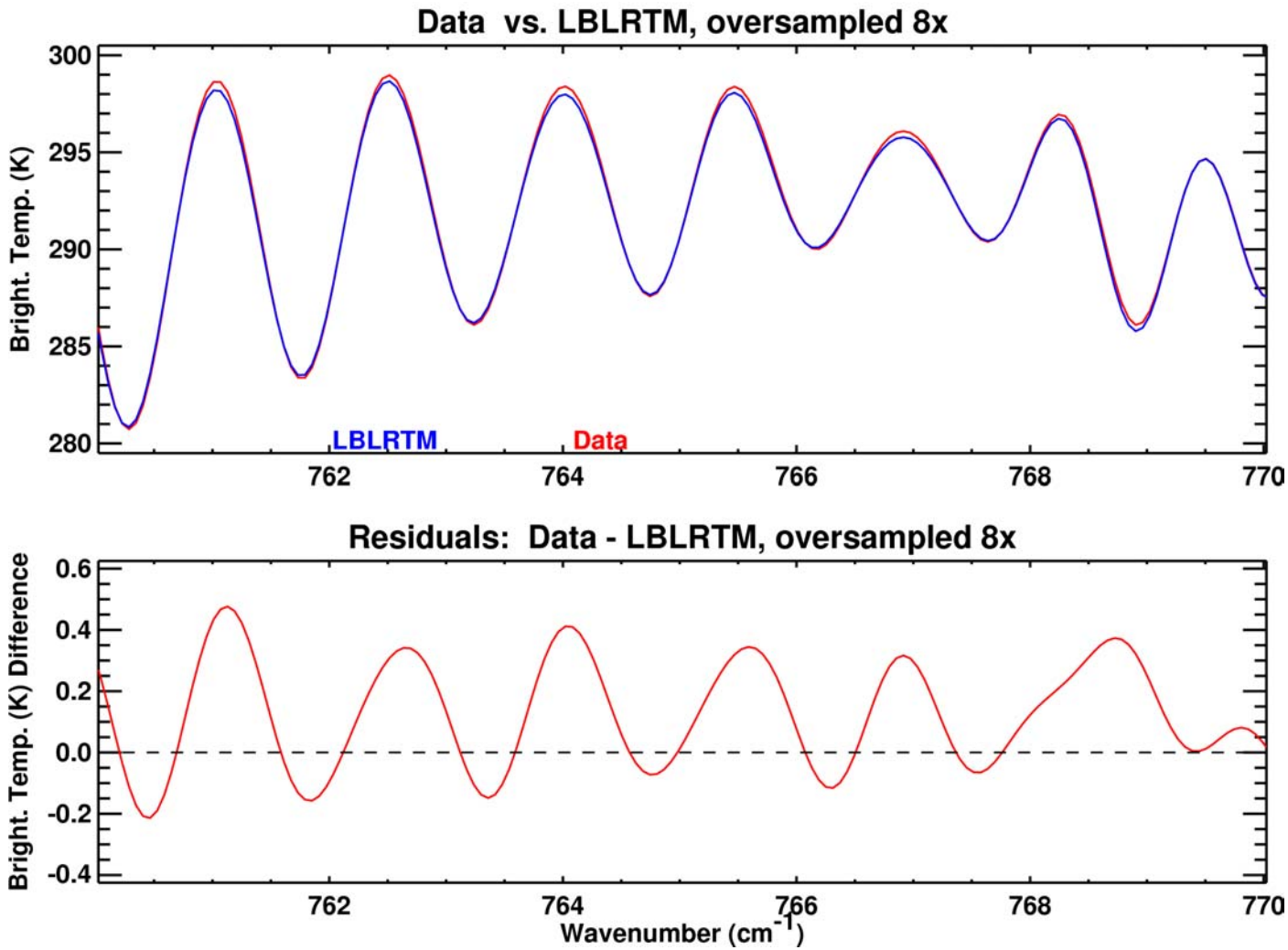
“comparison 0”

8 AIRS FOVs, 448 SHIS FOVs, PC filtering

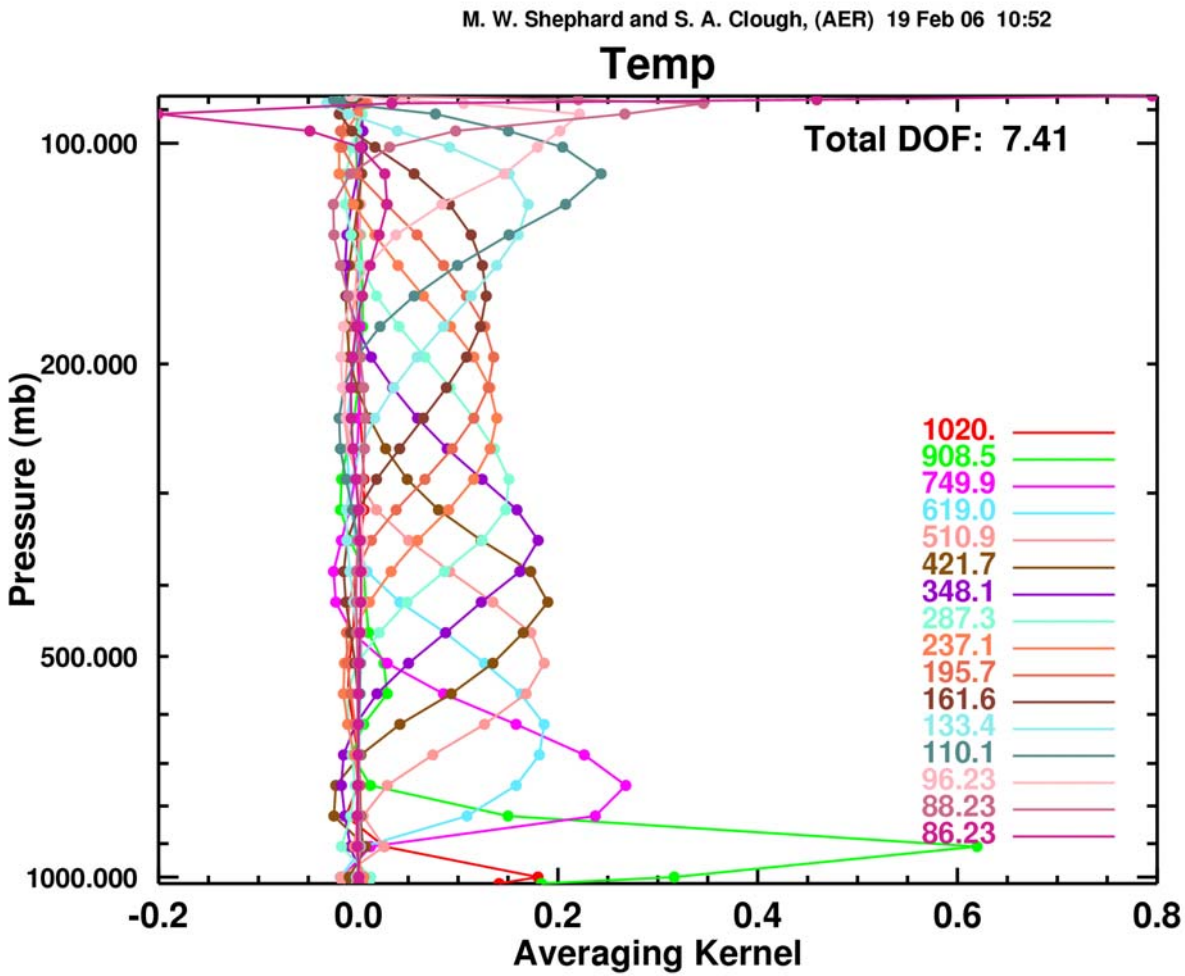


Detail View Before Spectroscopy

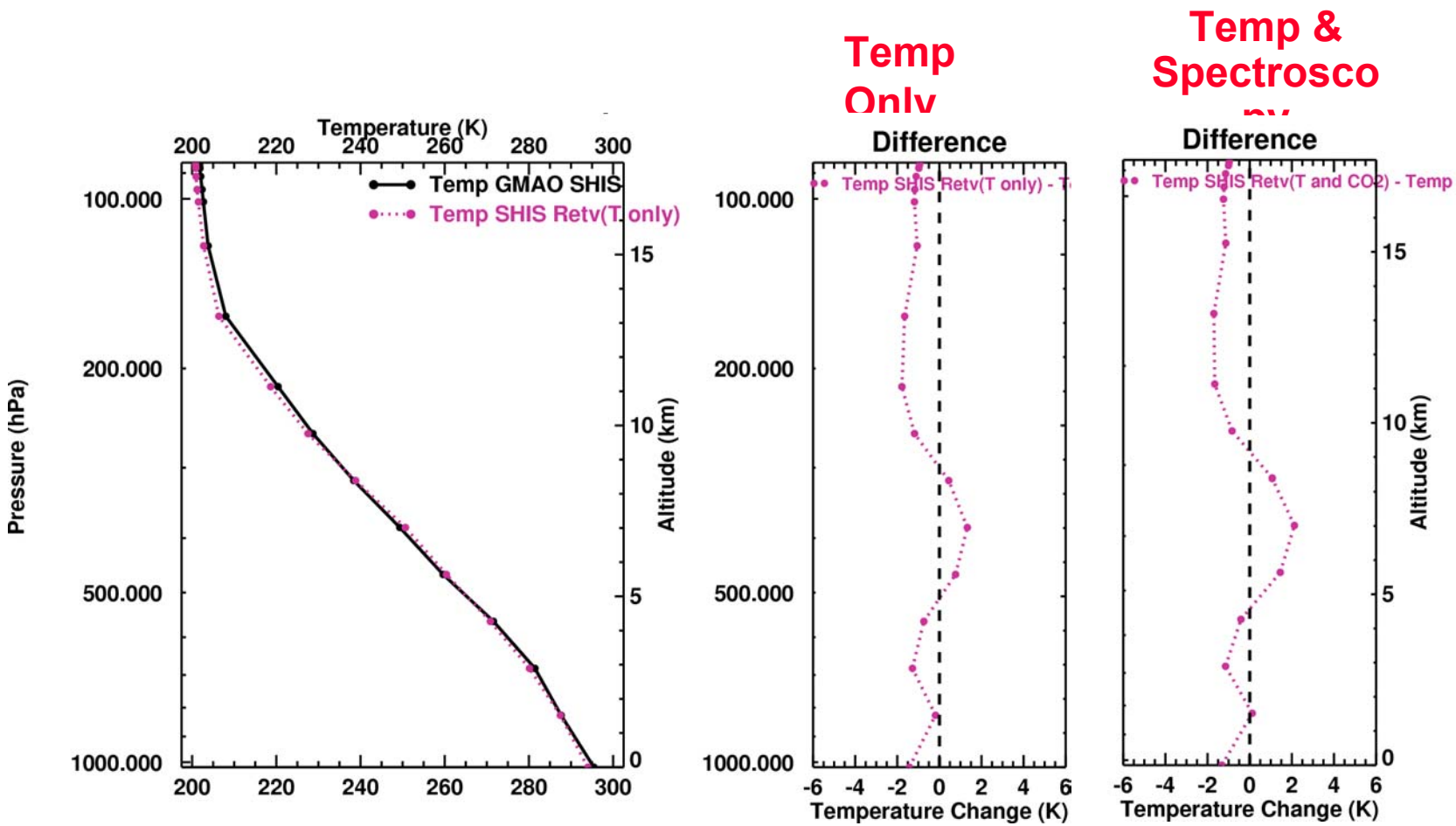
- **Further reduce residuals in the CO2 v2 spectral region**



Averaging Kernels for S-HIS

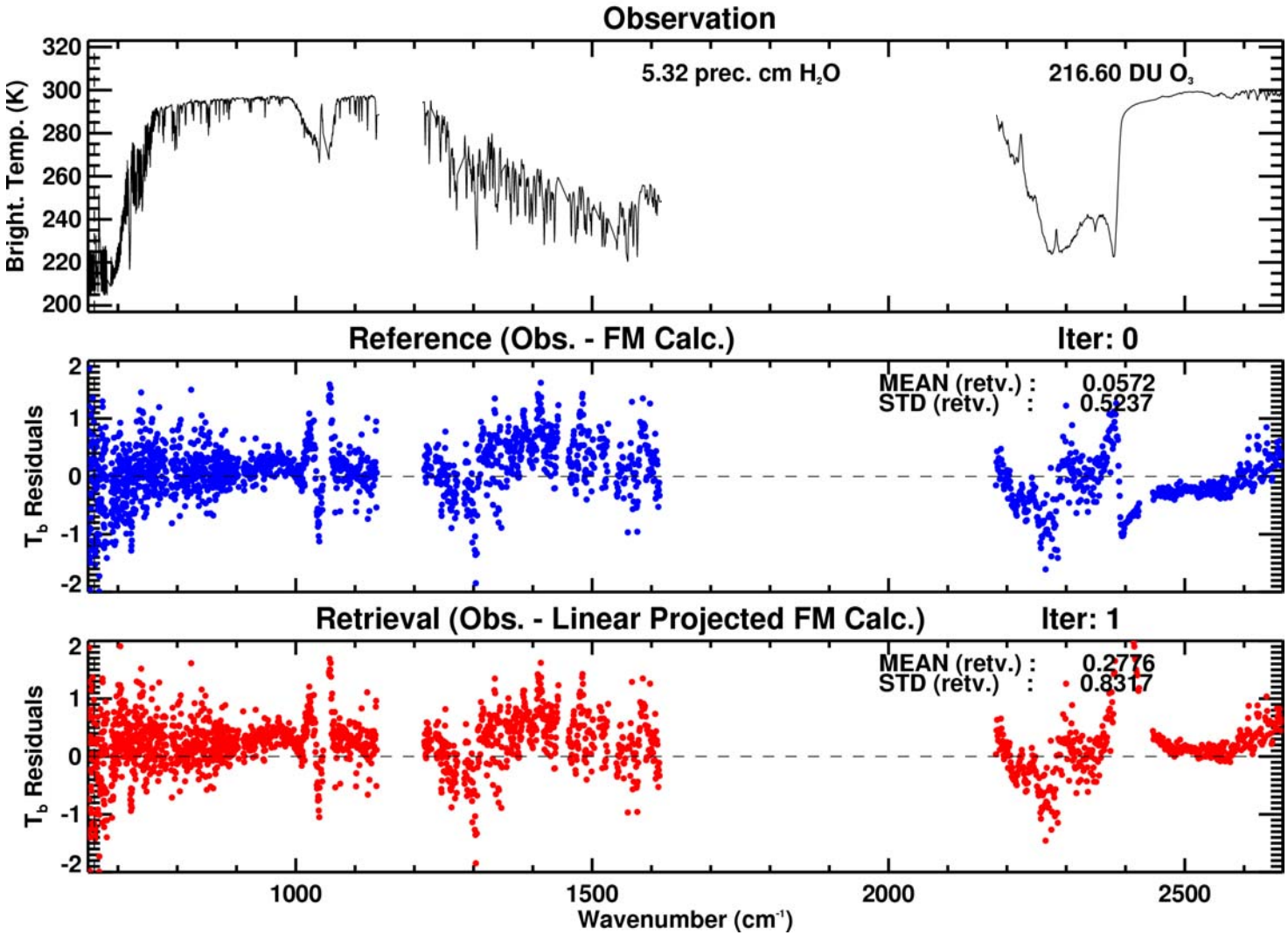


SHIS AVE Temperature Retrieval Results



AIRS: new spectroscopy

Atmosphere: sonde/adjusted ecmwf



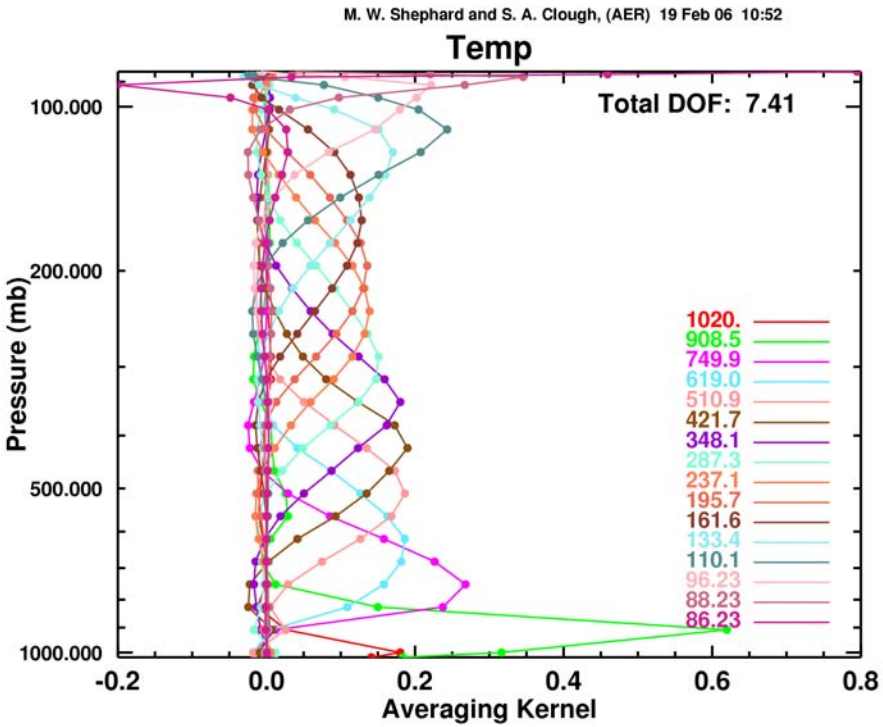
Reduction of Residuals in ν_2 Region

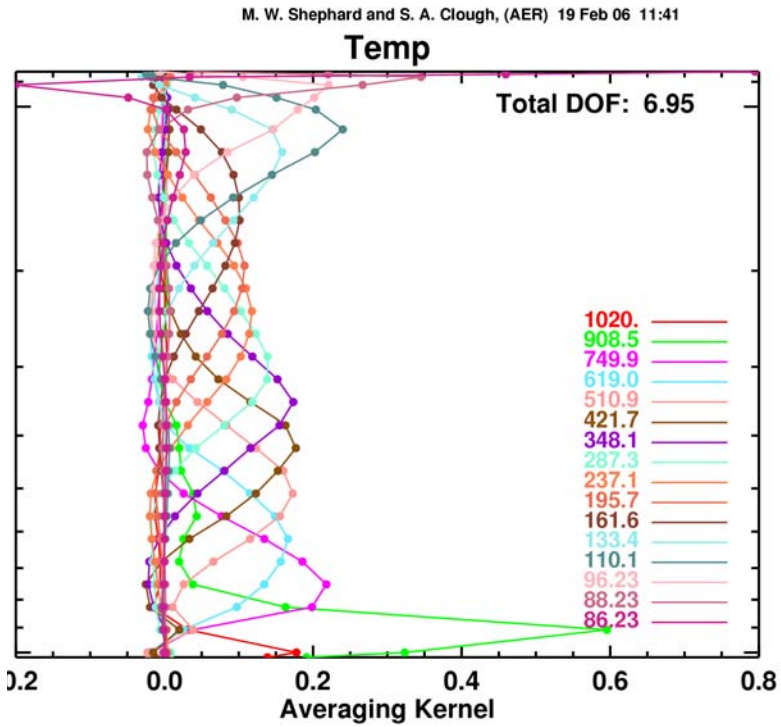
Simultaneous Retrieval of Temperature and Line Parameters

- **For each Vibration-Rotation Band ($8 \rightarrow 3$)**
  - **Line Strength (3 parameters)**
  - **Line Width (2 parameters)**

- **Global**
  - **P - R Line Coupling *(Hartmann)* (scaling)**
  - **Q Line Coupling *(Hartmann)* (scaling)**
  - **Halfwidth Temperature Dependence**
  - **CO_2 Continuum (scaling)**

Averaging Kernels





LBLRTM Validation : TES CO_2 v_2 Filter

TES Obs.

TES - LBLRTM

TES(SHIS ILS) - LBLRTM

SHIS - LBLRTM